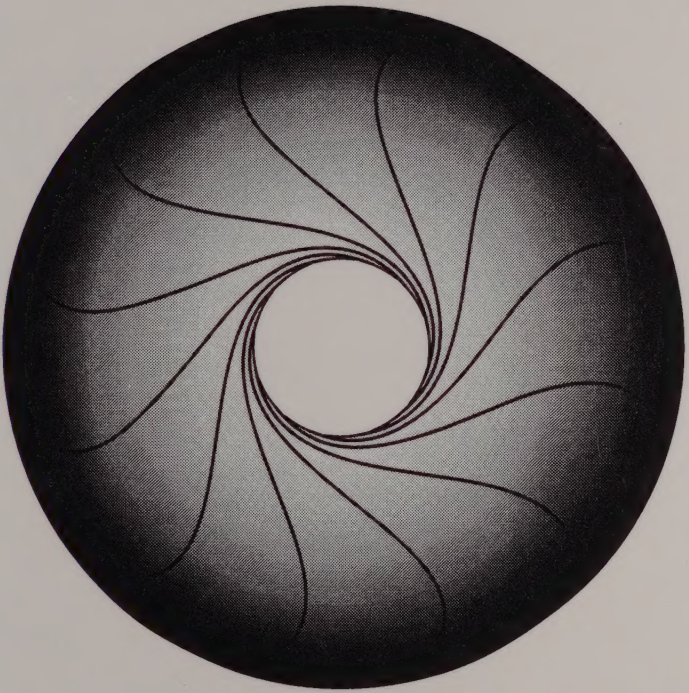
AdeptVision

User's Guide

Version 12.1



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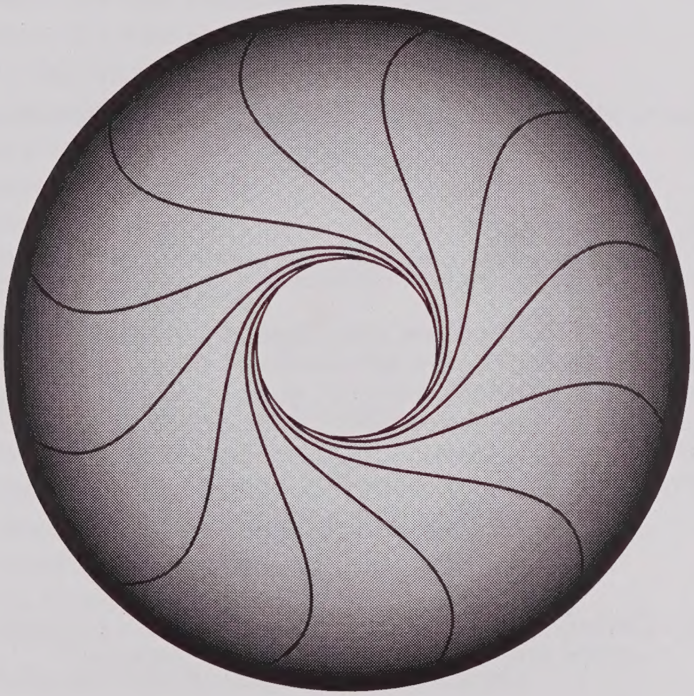

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Table of Contents

Introduction 19
Compatibility 20
What's New in AdeptVision VXL Version 12.x 21
    Version 12.0 New Features 21
    Version 12.1 New Features 21
How to Use This Manual 22
    Organization 22
    Before You Begin 23
    Related Manuals 23
    Safety 24
        Reading and Training for Users and Operators 24
        System Safeguards 25
Notes, Cautions, and Warnings 26
How Can I Get Help? 27
    Within the Continental United States 27
        Service Calls 27
        Application Questions 27
        Applications Internet E-Mail Address 27
        Training Information 28
    Within Europe 28
        France 28
    Outside Continental United States or Europe 28
    Adept Fax On Demand 28
    Adept On Demand Web Page 28

1 Overview 29
Introduction 30
What AdeptVision VXL Is 30
    Physical Equipment 30
    Controller and Vision Processor 32
    Robot or Motion Device 32
    Graphics Terminal 32
    User Equipment 33
What AdeptVision VXL Does 34
Vision Basics 35

Pixel 35
The Camera Imaging Surface 37
Resolution 37
Summary of Software Tools 39
Boundary Analysis 39
Rulers 39
Inspection Windows 39
Finder Tools 39
ObjectFinder 39
Processing Windows 40
Modeling 40
Overview of Guidance Vision 40
Frames 40
Things to Consider When Designing Your Workcell 41
Consistent Environment 41
Ease of Maintenance 41
Safety 41
Lighting 41

2 Installation 43

Setting up the Hardware 44
Installing the Controller 44
Attaching Cameras and Strobes 44
Strobe Compatibility 45
Cameras Supported by AdeptVision VXL 45
Panasonic GP-MF602 45
Panasonic GP-MF702 45
Pulnix TM-1001 46
Sony XC-77 46
Mounting Cameras 47
Setting Up the Software 48
System Memory 49

3 Getting Started 51

V$^+$ Syntax Conventions 52
Virtual Cameras 53
What Is a Virtual Camera? 53
How Are Camera Numbers Assigned? 54
Why Use Virtual Cameras? 54
Motion Devices and Calibration 54
Calibration 54

        Motion Device Calibration . . . 55
        Start-up Calibration . . . 55
        Camera Calibration . . . 55
    The Vision Transformation . . . 55
        Fixed-Mount Camera Transformation . . . 55
        Robot-Mounted Camera Transformation . . . 56
Loading Vision Calibration Data . . . 57

4 Vision Calibration Overview . . . 59

Compatibility . . . 60
Why Calibrate a Camera? . . . 60
    Millimeter-to-Pixel Ratio . . . 60
        When Do I Need the Millimeter-to-Pixel Ratio? . . . 62
    Perspective Distortion Corrections . . . 63
        When Do I Need the Perspective Distortion Corrections? . . . 63
    Camera-to-Robot Transformation . . . 64
        Fixed-Mount Cameras . . . 64
        Robot-Mounted Cameras . . . 64
Before You Start Calibrating Your Cameras . . . 65
    What You Need . . . 65
        Calibration Object . . . 65
    What You Need to Do . . . 67
    Things to Remember (Important Stuff) . . . 67
        When to Recalibrate the Camera . . . 67
        Virtual Cameras . . . 68
        Resolution, Accuracy, and Repeatability . . . 68

5 Using the Calibration Program . . . 71

ADV_CAL.V2 . . . 72
ADV_USER.V2 . . . 75
LOADAREA.V2 . . . 76

6 The ADV_CAL Menus . . . 81

Introduction . . . 83
Calibration Status Display . . . 83
Main Menu . . . 84
    Main Menu Options . . . 84
        Exit to system monitor . . . 84
        LOAD/STORE calibration data from/to disk . . . 85
        ADJUST camera/image settings . . . 86

CALIBRATE the current camera 86
TEST current calibration (camera-to-robot) 86
COPY calibration between virtual cameras 87
CHANGE virtual and/or physical cameras 88
SELECT different robot 88
ADJUST Camera/Image Menu 89
ADJUST Camera/Image Menu Options 89
RETURN to the main menu 89
ADJUST physical CAMERA ATTRIBUTES (live video) 89
ADJUST video GAIN and OFFSET (live video) 90
ADJUST binary THRESHOLD (live binary) 90
ADJUST vision WINDOW (processing boundaries) 90
CALIBRATE the Current Camera Menu 91
CALIBRATE the Current Camera Menu Options 95
Camera only 95
Stationary camera with robot — General method 95
Calibration object attached to robot (general case) 96
Downward-looking stationary camera (using vacuum gripper) . . 97
Object on moving belt (robot downstream of camera) 97
Robot mounted camera — Robot can touch calibration object . . 98
Robot mounted camera — Known dot location 99
Robot mounted camera—Non-contact method 99
Link-2 mounted camera—Robot can touch calibration object . . 100
Link-2 mounted camera—Known dot location 101
Link-2 mounted camera—Non-contact method (single config.) . 101
Link-2 mounted camera—Non-contact method (lefty/righty) . . . 102
LOAD/STORE Calibration Data Menu 102
LOAD/STORE Calibration Data From/To Disk Menu Options 103
LOAD calibration data from disk 103
STORE calibration data to disk 103

7 Calibration Results 105
Introduction 106
Vision Calibration Array 106
Perspective Transformations 108
Camera-to-Robot Transformation 109
Miscellaneous Global Variables 109
Location Array “ac.offset( )” 109
Location Array “ac.nominal( )” and Real Array “ac.config( )” 110

8 Teaching AdeptVision to See . . . 111

Introduction . . . 112
    Physical vs. Virtual Cameras . . . 112
    The Point of Origin . . . 113
VPICTURE—Getting an Image . . . 114
    VPICTURE Syntax . . . 114
        VPICTURE Examples . . . 115
    Executing VPICTURE From the Menu . . . 115
VDISPLAY—Displaying the Image . . . 115
    VDISPLAY Syntax . . . 116
        VDISPLAY Examples . . . 116
    Executing VDISPLAY From the Menu . . . 117
    Using the Different Display Modes . . . 117
        Live Modes . . . 117
        Frame (Frozen) Modes . . . 118
        Graphics Mode . . . 118
Binary vs. Grayscale Operations . . . 118
Switches and Parameters . . . 122
Using Switches . . . 123
    Enabling/Disabling Switches . . . 123
    Viewing Switch Settings . . . 123
        SWITCH Example . . . 124
    Image-Acquisition Switches . . . 124
Using Parameters . . . 125
    Setting Parameters . . . 125
        Parameter Examples . . . 125
    Image-Acquisition Parameters . . . 125
Examples of Switch and Parameter Settings . . . 127

9 Boundary Analysis . . . 135

Introduction . . . 136
    Switches and Parameters Used During Boundary Analysis . . . 136
Boundary Analysis Instructions . . . 138
    VLOCATE . . . 138
        VLOCATE Examples . . . 139
    The DO Monitor Command . . . 140
    VFEATURE . . . 140
        What is VFEATURE? . . . 140
        Blob Allocation . . . 142
        VFEATURE Example . . . 142
    VQUEUE . . . 143

10 Vision Tools . . . 145

Defining a Tool Area-of-Interest (AOI) . . . 146
- Frame Stores . . . 146
  - Virtual Frame Buffers . . . 146
- Areas-of-Interest . . . 147
  - Defining an Image Buffer Region . . . 149

Linear Rulers . . . 152
- VRULERI Array . . . 152
- Linear Ruler Example . . . 153

Arc Rulers . . . 155
- Arc Ruler Example . . . 155

Ruler Types . . . 158
- Standard Binary Rulers (type = 0) . . . 158
- Raw Binary Rulers (type = −1) . . . 158
- Dynamic Binary Rulers (type = −2) . . . 158
- Graylevel Rulers (type = 1) . . . 159
- Fine Edge/Fine Pitch Rulers (type = 2/3) . . . 159
  - Ruler Speed and Accuracy . . . 160

Finder Tools . . . 160
- VFIND.LINE Array . . . 161
- Line Finder Tool Polarity . . . 161
- VFIND.LINE Example . . . 162

Processing Windows (VWINDOW) . . . 164
- VWINDOW Example . . . 164

Vision Tools: Inspection Windows (VWINDOWI) . . . 165

Vision Tool Data Arrays . . . 165

Windows, Windows, Windows . . . 166

11 Vision Model Processing . . . 167

Introduction . . . 169
- Why Use Prototype Recognition? . . . 169
- Why Use Correlation? . . . 170
- Why Use OCR? . . . 170

Training Prototypes . . . 170
- Creating Prototypes . . . 171
- Editing Prototypes . . . 172
- Preview Window . . . 175
- Zoom Buttons . . . 175
- Message Window . . . 175
- Edit Buttons . . . 175
- Editing Operation Data Box . . . 176

Edge/Region Data Boxes 176
Edge/Region Radio Buttons 176
Prototype Training Hints 177
SubPrototypes 177
Prototype Parameters 177
Setting Prototype Parameters 177
Verify percent 178
Effort level 178
Min/max area 178
Limit position 178
Edge weights 178
Assign cameras 178
Using Prototypes 179
Recognizing a Prototype 179
Prototype-Relative Inspection 180
Prototype-Relative Part Acquisition 180
Performing Correlation Matches 181
Creating a Correlation Template 181
Matching a Correlation Template 181
Performing Optical Character Recognition 183
Training an OCR Font 183
Font Planning 184
Character Recognition 185
OCR Examples 186
Prototype Model Switches and Parameters 187
Loading and Storing Vision Models 189
VSTORE 189
VLOAD 190
Displaying Vision Models 191
Deleting Vision Models 191
Renaming Vision Models 192

12 Programming AdeptVision VXL 193
Introduction 194
Application Development Strategy 194
Vision Inspection Example Program 195
Developing the Program Code 198
Program Header and Variables Declarations 198
Set the Camera Environment 199
Acquire an Image and Start Processing 200
Locate the Object and Begin Inspections 201
Output the Results 208

Further Programming Considerations . . . 210
The Complete Inspection Vision Program . . . 211
The Main Program - inspect.part . . . 211
Subroutine - line.line . . . 218
Subroutine - init.program . . . 220
Subroutine - write.vwin . . . 221

13 Guidance Vision . . . 223
Introduction . . . 224
Using a Fixed-Mount Camera . . . 225
4-Axis SCARA Robot with Camera on Link #2 . . . 229
5-Axis SCARA Robot with Camera on Link #2 . . . 234
Guidance Vision Program . . . 236
The Sample Program . . . 237
Further Programming Considerations . . . 246
Error Handling . . . 246
Generalizing the Program . . . 246

14 Advanced Operations . . . 249
Performing High-Speed Inspections . . . 250
What is “High Speed”? . . . 250
Using the Two Frame Store Areas . . . 251
Using VPICTURE With Different Frame Stores . . . 252
Using VDISPLAY With Different Frame Stores . . . 252
Sample Code for a High-Speed Inspection . . . 252
The High-Speed Trigger . . . 254
Performing Frame-Relative Inspections . . . 255
Blob-Relative Inspection . . . 255
Prototype-Relative Inspection . . . 257
Frame-Relative Inspections Using VDEF.TRANS . . . 258
Using a Vision-Guided Tracking Conveyor . . . 260

A Switches and Parameters . . . 261
Setting Vision Switches . . . 262
Viewing Switch Settings . . . 262
Setting Vision Parameters . . . 262
Viewing Parameters . . . 263
List of Switches . . . 263
List of Parameters . . . 266

B VFEATURE( ) Values . . . 269

Viewing VFEATURE( ) Values . . . 270
Establishing VFEATURE( ) Values . . . 270

C ObjectFinder Primer . . . 279

Introduction . . . 280
Object Recognition . . . 280
  Feature Processing . . . 280
  Step 1: Hypothesis Generation . . . 281
    Feature Classes . . . 281
    Proposals . . . 281
    Seeds . . . 281
  Step 2: Confirmation . . . 281
  Step 3: Refinement . . . 282
  Step 4: Verification . . . 282
    Max Verify Dist and Verify Percent . . . 282

D Lens Selection . . . 283

Introduction . . . 284
Formula for Focal Length . . . 284
Formula for Resolution . . . 286

E Lighting Considerations . . . 289

Types of Lighting . . . 290
Lighting Strategies . . . 290
  Diffuse . . . 290
  Back . . . 291
  Directional . . . 291
  Structured . . . 291
  Strobe . . . 291
Filtering and Special Effects . . . 292
  Polarizing Filters . . . 292
  Color Filters . . . 292

F Calibrating With HPS Data . . . 293

Introduction . . . 294
Using HPS Data . . . 294

G Calibration Target Dimensions . . . 297
The Calibration Target . . . 298
Using a Custom Calibration Sheet . . . 299

H Camera Calibration Programs . . . 301
adv.cam.sample( ) . . . 302
ac.refine.vloc( ) . . . 303
adv.cam.user( ) and adv.tr.point( ) . . . 305
    adv.cam.user( ) . . . 305
    adv.tr.point( ) . . . 308

I Pulnix TM-1001 Configuration . . . 311
Introduction . . . 312
Overview . . . 312
Switch Settings . . . 313
    DSP/NSP Switch . . . 313
    NRM/ASY Switch . . . 313
    Shutter Control . . . 314
        For Asynchronous Reset Mode . . . 314
        For Normal (Synchronous) Mode . . . 314
EVI Module Settings . . . 315
Camera Cables . . . 315
Changes to Frame Buffer Size . . . 315
Blob Analysis Using the Pulnix TM-1001 . . . 316

J Using DEVICE With Vision . . . 317
Introduction . . . 318
The DEVICE Instruction With Vision . . . 318
    Defective Pixel Compensation . . . 321
        Writing a Table Entry . . . 321
        Reading a Table Entry . . . 322
        Resetting a Table Entry . . . 322
        Error Information . . . 322
    Example: Changing the Number of Virtual Frame Stores . . . 323

K Memory Allocation 325
L Vision Window Menus 327
M Third-Party Suppliers 333
Third-Party Suppliers (U.S.) 334
Third-party Suppliers (Europe) 339
Third-Party Suppliers (Asia-Pacific) 343

Index 345

List of Figures

Figure 1. Impact and Trapping Hazards . . . 26
Figure 1-1. Typical AdeptVision VXL System . . . 31
Figure 1-2. Sample Object . . . 35
Figure 1-3. A Grayscale Image . . . 36
Figure 1-4. A Binary Image . . . 36
Figure 1-5. Resolution Factors . . . 38
Figure 2-1. Initial Screen . . . 48
Figure 3-1. Sample Operation . . . 52
Figure 3-2. Physical/Virtual Camera Relationship . . . 53
Figure 4-1. Millimeter-to-Pixel Ratio . . . 61
Figure 4-2. Perspective Distortion . . . 63
Figure 8-1. VPICTURE Options . . . 115
Figure 8-2. Display Mode Options . . . 117
Figure 8-3. Sample Vision Matrix . . . 118
Figure 8-4. Binary Representation of Sample Matrix . . . 119
Figure 8-5. Grayscale Representation of Sample Matrix . . . 120
Figure 8-6. Sample Object . . . 127
Figure 8-7. Switch and Parameter Example 1 . . . 128
Figure 8-8. Switch and Parameter Example 2 . . . 129
Figure 8-9. Switch and Parameter Example 3 . . . 130
Figure 8-10. Switch and Parameter Example 4 . . . 131
Figure 8-11. Switch and Parameter Example 5 . . . 132
Figure 8-12. Switch and Parameter Example 6 . . . 133
Figure 8-13. Switch and Parameter Example 7 . . . 134
Figure 10-1. Rectangular Area-of-Interest Shapes . . . 148
Figure 10-2. Arc-Shaped Area-of-Interest Shapes . . . 148
Figure 10-3. Sample Area-of-Interest . . . 150
Figure 10-4. Sample Image Buffer Regions . . . 151
Figure 10-5. Linear Ruler Example . . . 154
Figure 10-6. Sample Gauge Face . . . 155
Figure 10-7. Arc Ruler Example . . . 157
Figure 10-8. Ruler Types . . . 159
Figure 10-9. Line Finder Search Area . . . 161
Figure 10-10. Finder Tool Polarity . . . 162
Figure 10-11. Line Finder Example . . . 163
Figure 10-12. VWINDOW Example . . . 165
Figure 11-1. Prototype Editing Operations . . . 174
Figure 11-2. Font Similarity Matrix . . . 185
Figure 12-1. Application Flow Chart . . . 197

Figure 12-2. Executing the VWINDOW Instruction 202
Figure 12-3. Executing a VFIND.LINE Instruction 205
Figure 12-4. Executing a VFIND.ARC Instruction 207
Figure 12-5. Calculating the Object Tail Location 219
Figure 13-1. Fixed-Mount Camera (Vision Location) 227
Figure 13-2. Fixed-Mount Camera Vision Transformation 228
Figure 13-3. Link2 Coordinate Frame 231
Figure 13-4. Calculating the "Link2" Transformation 232
Figure 13-5. Components of the Vision Location 233
Figure 13-6. Final Part Acquire Location 234
Figure 13-7. Five-Axis Vision Transformation 235
Figure 13-8. Example Program Setup 237
Figure 14-1. Ping-Pong Frame Grabbing 251
Figure 14-2. Blob-Relative Inspection 257
Figure D-1. Camera Imaging 285
Figure D-2. Camera Scale Factor 285
Figure I-1. Pulnix TM-1001 Camera Connectors and Switches 313

List of Tables

Table 7-1. Elements of Vision Calibration Array 106
Table 8-1. Image-Acquisition Switches 124
Table 8-2. Image-Acquisition Parameters 126
Table 9-1. Boundary Analysis Switches 136
Table 9-2. Boundary Analysis Parameter 137
Table 9-3. VFEATURE Values and Interpretation 141
Table 11-1. Prototype Model Switches 187
Table 11-2. Prototype Model Parameters 188
Table A-1. Vision Switches 263
Table A-2. Vision Parameters 266
Table B-1. VFEATURE( ) Values and Interpretation for Prototype Recognition Instances (following VLOCATE) 271
Table B-2. VFEATURE( ) Values and Interpretation for Prototype Recognition Instances (following VSHOW) 273
Table B-3. VFEATURE( ) Values and Interpretation for ObjectFinder Recognition Instances (following VLOCATE) 275
Table B-4. VFEATURE( ) Values and Interpretation for ObjectFinder Models (following VSHOW) 276
Table D-1. Camera Scale Factors 286
Table E-1. Types of Lighting 290
Table G-1. Adept Calibration Sheet Dimensions 298
Table I-1. Shutter Dial Settings for Asynchronous Mode 314
Table J-1. DEVICE Input/Output Format 320
Table J-2. Vision Memory Allocation 320
Table K-1. Vision System Memory Allocation 325
Table M-1. Fiber Optic Lighting Suppliers 334
Table M-2. Lighting Suppliers 335
Table M-3. Camera Equipment Suppliers 335
Table M-4. Frame Splitter Suppliers 336
Table M-5. Camera Suppliers 336
Table M-6. Filter and Optics Suppliers 337
Table M-7. Lens Suppliers 337
Table M-8. Mounting Hardware Suppliers 339
Table M-9. Lighting Suppliers 339
Table M-10. Lens Suppliers 340
Table M-11. Filter and Optics Suppliers 340
Table M-12. Lighting, Filter, and Optics Suppliers 343

Introduction

Compatibility 20
What's New in AdeptVision VXL Version 12.x 21
    Version 12.0 New Features 21
    Version 12.1 New Features 21
How to Use This Manual 22
    Organization 22
    Before You Begin 23
    Related Manuals 23
    Safety 24
        Reading and Training for Users and Operators 24
        System Safeguards 25
Notes, Cautions, and Warnings 26
How Can I Get Help? 27
    Within the Continental United States 27
        Service Calls 27
        Application Questions 27
        Applications Internet E-Mail Address 27
        Training Information 28
    Within Europe 28
        France 28
    Outside Continental United States or Europe 28
    Adept Fax on Demand 28
    Adept on Demand Web Page 28

Compatibility

This manual is for use with V$^+$ systems equipped with the AdeptVision software and hardware options. The system version must be 12.1 or later.

This manual is intended primarily for vision application programmers. If your system includes the optional VisionWare or MotionWare with vision software, you do not need to read this manual. However, many principles of machine vision and AdeptVision VXL processing are covered in greater detail here than in the VisionWare or MotionWare user's guides, so a general review of this manual may be useful.

What's New in AdeptVision VXL Version 12.x

This section summarizes the new features in AdeptVision VXL version 12.0 and later.

Version 12.0 New Features

- Supports the new Enhanced Vision Interface (IMV/EVI) board. See the *Adept MV Controller User's Guide* for details.

  NOTE: Support is maintained for old versions of the vision (VIS) board. The software automatically detects which board is present.

  With the IMV/EVI board present and no EVI software license, the system functions as though a VIS board is present.

  With the IMV/EVI board present and an EVI software license, the system provides:

  - Twice the frame buffer memory versus the VIS board
  - 1K x 1K camera support. This includes: 1K x 1K frame buffers and image acquisition; support for Pulnix TM-1001 cameras; defective-pixel compensation software.
  - Convolutions run nine times faster
  - Larger (5 x 5 and 7 x 7) convolutions
  - Faster hierarchical correlation
  - Perimeter calculations using VWINDOWB
- Supports AdeptWindows. See the *AdeptWindows User's Guide* for more information on this product.

Version 12.1 New Features

- Supports the ObjectFinder tool. See Appendix C for details.
- ENABLE VISION monitor command modified to minimize reinitialization time. Frame grabber testing now done only at startup.
- Larger default total memory size allocated to vision. This is user-adjustable with the CONFIG_C utility.
- Larger blob and run length allocation limits. This is user-adjustable with the CONFIG_C utility and the DEVICE command.

How to Use This Manual

Organization

Material in this manual is presented in a step-by-step fashion. Each chapter expands on and relies on information in the preceding chapters. If you are new to machine vision systems, this manual will take you from the conceptual basis for machine vision to advanced programming techniques in computer vision applications. Here is what you will find in each of the chapters:

Chapter 1	presents an overview of machine vision principles and introduces vocabulary and concepts you will need when reading the other chapters.
Chapter 2	shows you how to physically set up the AdeptVision VXL system hardware.
Chapter 3	shows you how to perform all the initialization tasks necessary to get your system ready to start developing vision applications.
Chapter 4	provides an overview of vision system calibration. The vision system should always be calibrated prior to any application development.
Chapter 5	describes the overall procedure for executing the Advanced Camera Calibration program (ADV_CAL.V2).
Chapter 6	describes each of the selections in the ADV_CAL menus.
Chapter 7	describes the data generated during the calibration process. This data includes calibration arrays, perspective transformations, and (for robot-related calibrations) camera-to-robot transformations.
Chapter 8	introduces vision processing. It describes how to acquire and process an image. You will learn to fine-tune the images you produce so your vision applications run as efficiently and predictably as possible.
Chapter 9	describes the first vision processing strategy, boundary analysis. You will learn where vision data is stored and how you can influence the data the vision system gathers.
Chapter 10	describes the second vision processing strategy, vision tools. You will learn to use rulers, finders, and inspection windows.

Chapter 11	describes the vision modeling process, including prototype recognition, optical character recognition (OCR), and correlation templates.
Chapter 12	presents a sample program. You will learn how to combine the knowledge gained in the previous chapters to program an inspection vision application.
Chapter 13	covers using the vision system to guide a motion device. You will learn how to set up and calibrate cameras that will locate, acquire, and place parts. If you do not have a motion device, you can skip this chapter.
Chapter 14	discusses advanced topics in vision processing. High-speed inspections, part-relative inspections, and conveyor operations are covered.

Before You Begin

AdeptVision VXL is an extension of the V$^+$ operating system and language. In order to use the AdeptVision VXL extension you must be familiar with the basic V$^+$ operating system and language. In particular, this manual assumes that you:

- Are familiar with the Adept graphical user interface.
- Can use the SEE program editor or the AdeptWindows Offline Editor to create and edit programs.
- Are familiar with V$^+$ programming, including control structures, data types, and subroutine principles.

The V$^+$ operating system and graphical user interface are covered in the *V$^+$ Operating System User's Guide* and the *V$^+$ Operating System Reference Guide.* The V$^+$ language is covered in the *V$^+$ Language User's Guide* and the *V$^+$ Language Reference Guide.*

Related Manuals

There are several manuals you should have handy as you use this manual. They are:

- The *V$^+$ Operating System User's Guide,* which covers operating system tasks such as copying files, executing programs, and using the graphical interface.
- The *V$^+$ Operating System Reference Guide,* which details the operating system commands (known as monitor commands).

- The *V⁺ Language User's Guide* and the *V⁺ Language Reference Guide,* which contain a complete description of the commands, instructions, functions, and other features available in the V⁺ language. These manuals are essential for advanced applications programming.
- The *AdeptVision Reference Guide,* which contains a complete description of the vision enhancements to the V⁺ language. This manual is a companion guide to the *AdeptVision User's Guide.*
- The *Instructions for Adept Utility Programs,* many of which are referenced in this manual.
- The *Adept MV Controller User's Guide.* This manual contains information on installing, maintaining, and configuring the physical controller hardware.
- The *AdeptWindows User's Guide.* This manual contains information on installing and using the AdeptWindows software package. This software allows you to use a PC front end with the Adept MV controller. It also allows you to write and edit V⁺ code offline using the PC.
- The user's guide for your robot or motion device (if your system includes a motion device). This manual contains information on installing, maintaining, and calibrating the motion device.
- The manuals for any options you have purchased with the system (such as VisionWare), or purchased separately to use with the system.

Safety

Reading and Training for Users and Operators

Adept systems may contain computer-controlled robot mechanisms that are capable of moving at high speeds and exerting considerable force. Like all robot systems and most industrial equipment, they must be treated with respect by the user and the operator.

This manual should be read by all personnel who operate or maintain Adept robot systems, or who work within or near the robot workcell.

We also recommend you read the *American National Standard for Industrial Robot Systems - Safety Requirements,* published by the Robotic Industries Association (RIA), in conjunction with the American National Standards Institute. The publication, ANSI/RIA R15.06 - 1986, contains guidelines for robot system installation, safeguarding, maintenance, testing, startup, and operator training. The document is available from the American National Standards Institute, #13THF, 11 West 42nd Street, New York NY 10036-8002.

NOTE: This manual follows RIA definitions of "user" as the responsible person or company and "operator" as a person who starts, stops, or monitors robot operation.

This manual assumes that the user has attended an Adept training course and has a basic working knowledge of the robot system. The user should provide the necessary additional training for all personnel who will be working with the system.

System Safeguards

Safeguards should be an integral part of robot workcell design, installation, operator training, and operating procedures.

Adept robot systems have various communication features to aid in constructing system safeguards. These include remote emergency stop circuitry and digital input and output lines. These features are described in the controller user's guide.

Because Adept robots are computer-controlled, the program that is currently running the robot may cause it to move unexpectedly. When the amber HIGH POWER and the blue "Program Running" lights on the optional Adept front panel are lit, the robot might move. When these lights are lit, no one should enter the workcell, because they cannot predict when or where the robot might move. The LAMP TEST button allows this light to be periodically checked (see the controller user's guide).

In addition, these systems can be programmed to control equipment or devices other than the robot. As with the robot, the program controlling these devices may cause them to operate unexpectedly. It is critical that safeguards be in place to prevent personnel from entering the workcell when a program is running. The blue PROGRAM RUNNING light on the front of the optional front panel indicates the program is running. The LAMP TEST button allows this light to be periodically checked.

WARNING: Entering the robot workcell when either the HIGH POWER or the PROGRAM RUNNING light is on can result in severe injury.

Adept Technology highly recommends the use of additional safety features such as light curtains, safety gates, or safety floor mats to prevent entry to the workcell while ARM POWER is enabled. These devices may be connected using the system's remote emergency stop circuitry. See the *Adept MV Controller User's Guide.*

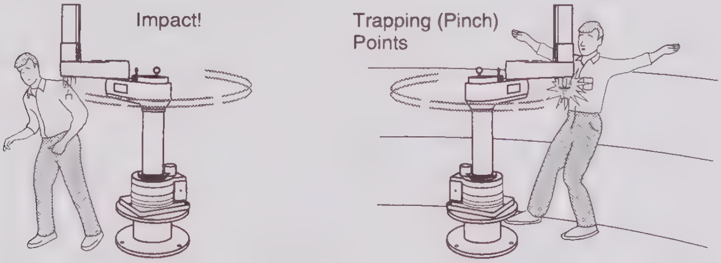


Figure 1. Impact and Trapping Hazards

Notes, Cautions, and Warnings

There are two levels of special notation used in this manual. They are:

WARNING: If the actions indicated in a "WARNING" are not complied with, injury or major equipment damage could result. A warning statement typically describes the hazard, its possible effect, and the measures that must be taken to reduce the hazard.

CAUTION: If the action specified in the "CAUTION" is not complied with, damage to your equipment could result.

NOTE: A "NOTE" provides supplementary information, emphasizes a point or procedure, or gives a tip for easier operation.

How Can I Get Help?

The following section tells you who to call if you need help.

Within the Continental United States

Adept Technology maintains a Customer Service Center at its headquarters in San Jose, CA. The phone numbers are:

Service Calls

(800) 232-3378 (24 hours a day, 7 days a week)
(408) 433-9462 FAX

> **NOTE:** When calling with a controller-related question, please have the serial number of the controller. If your system includes an Adept robot, also have the serial number of the robot. The serial numbers can be determined by using the ID command (see the *V$^+$ Operating System User's Guide*).

Application Questions

If you have an application question, you can contact the Adept Applications Engineering Support Center for your region:

Adept Office	Phone #, Hours	Region
San Jose, CA	Voice (408) 434-5033 Fax (408) 434-6248 8:00 A.M. – 5:00 P.M. PST	Western Region States: AR, AZ, CA, CO, ID, KS, LA, MO, MT, NE, NM, NV, OK, OR, TX, UT, WA, WY
Cincinnati, OH	Voice (513) 792-0266 Fax (513) 792-0274 8:00 A.M. – 5:00 P.M. EST	Midwestern Region States: AL, IA, IL, IN, KY, MI, MN, MS, ND, West NY, OH, West PA, SD, TN, WI
Southbury, CT	Voice (203) 264-0564 Fax (203) 264-5114 8:00 A.M. – 5:00 P.M. EST	Eastern Region States: CT, DE, FL, GA, MD, ME, NC, NH, MA, NJ, East NY, East PA, RI, SC, VA, VT, WV

Applications Internet E-Mail Address

If you have access to the Internet, you can send application questions by e-mail to:

`adeptinfo@infolab.com`

This method also enables you to attach a file, such as a portion of V$^+$ program code, to your message.

> **NOTE:** Please attach only information that is formatted as text.

Training Information

For information regarding Adept Training Courses in the USA, please call (408)474-3246 or send a FAX message to (408)474-3226.

Within Europe

Adept Technology maintains a Customer Service Center in Dortmund, Germany. The phone numbers are:

(49) 231 / 75 89 40 from within Europe (Monday to Friday, 8:00 A.M. to 5:00 P.M.)
(49) 231/75 89 450 FAX

France

For customers in France, Adept Technology maintains a Customer Service Center in Massy, France. The phone numbers are:

(33) 1 69 19 16 16 (Monday to Friday, 8:30 A.M. to 5:30 P.M., CET)
(33) 1 69 32 04 62 FAX

Outside Continental United States or Europe

For service calls, application questions, and training information, call the Adept Customer Service Center in San Jose, California USA:

1 (408) 434-5000
1 (408) 433-9462 FAX (service requests)
1 (408) 434-6248 FAX (application questions)

Adept Fax on Demand

Adept maintains a fax back information system for customer use. The phone numbers are (800) 474-8889 (toll free) and (503)207-4023 (toll call). Application utility programs, product technical information, customer service information, and corporate information is available through this automated system. There is no charge for this service (except for any long-distance toll charges). Simply call either number and follow the instructions to have information faxed directly to you.

Adept on Demand Web Page

If you have access to the Internet, you can view Adept's web page at the following address:

`http://www.adept.com`

The web site contains sales, customer service, and technical support information.

Overview 1

Introduction . . . 30

What AdeptVision VXL Is . . . 30

- Physical Equipment . . . 30
- Controller and Vision Processor . . . 32
- Robot or Motion Device . . . 32
- Graphics Terminal . . . 32
- User Equipment . . . 33

What AdeptVision VXL Does . . . 34

Vision Basics . . . 35

- Pixel . . . 35
- The Camera Imaging Surface . . . 37
- Resolution . . . 37

Summary of Software Tools . . . 39

- Boundary Analysis . . . 39
- Rulers . . . 39
- Inspection Windows . . . 39
- Finder Tools . . . 39
  - ObjectFinder . . . 39
- Processing Windows . . . 40
- Modeling . . . 40

Overview of Guidance Vision . . . 40

- Frames . . . 40

Things to Consider When Designing Your Workcell . . . 41

- Consistent Environment . . . 41
- Ease of Maintenance . . . 41
- Safety . . . 41
- Lighting . . . 41

Introduction

This section presents an overview of machine vision. It gives a brief description of how a vision system "sees" and what equipment and software tools you have for extracting information about what the vision system "sees".

What AdeptVision VXL Is

Physical Equipment

A basic AdeptVision VXL system consists of:

- A controller equipped with a vision processor board
- A robot or motion device (optional)
- One or more cameras
- A graphics-based controller option that includes:
  - A high-resolution color monitor
  - An AT-compatible keyboard
  - A trackball (or other pointing device)

In addition, your system will probably contain special lighting equipment and camera mounting equipment. This vision system is generally integrated with parts delivery systems and other user-supplied equipment to form a workcell that performs the tasks you have designated for the system. The major components an AdeptVision VXL system may have are described below. Figure 1-1 shows a typical system.

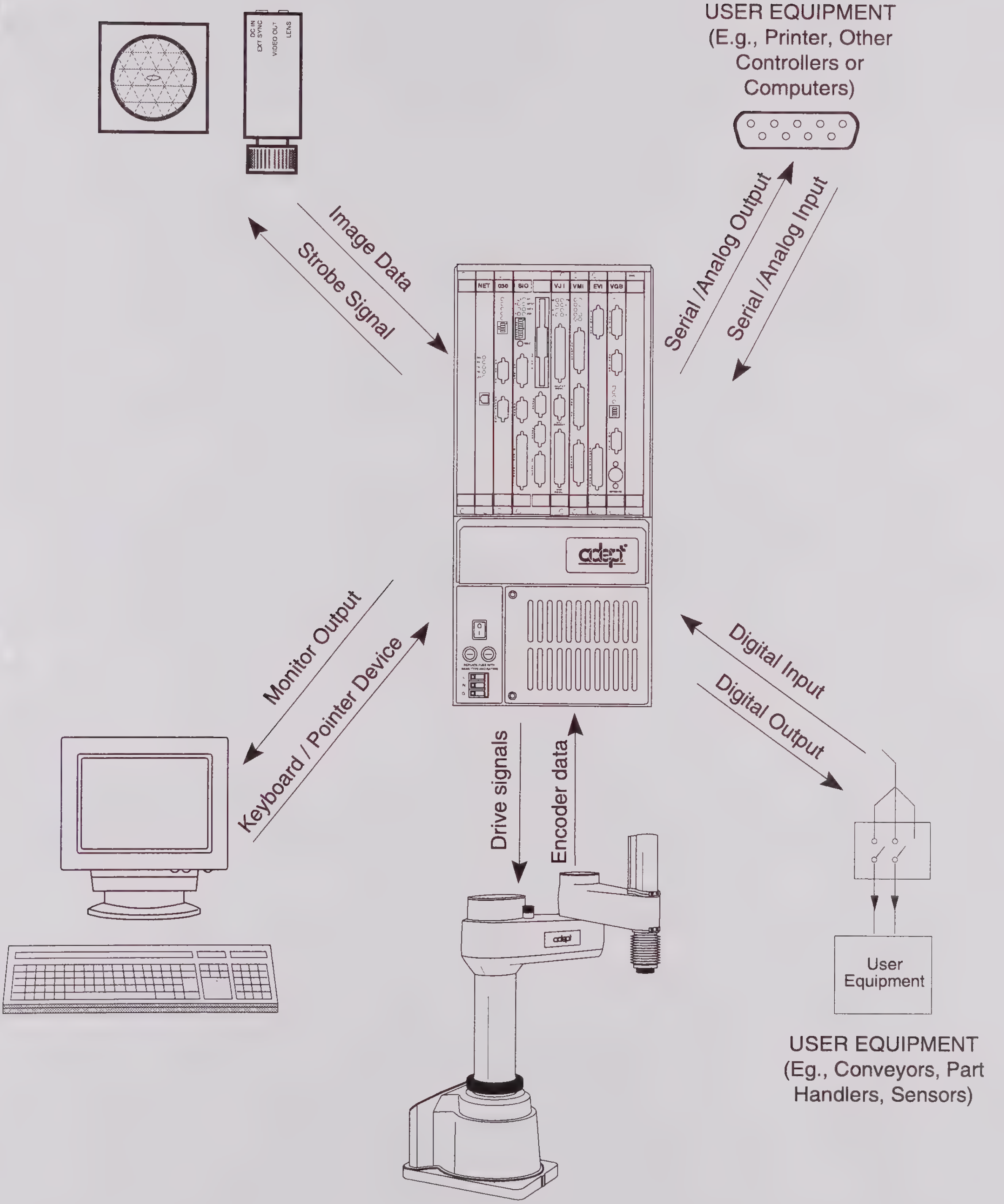

DC IN
EXT SYNC
VIDEO OUT
LENS
USER EQUIPMENT
(E.g., Printer, Other Controllers or Computers)
Image Data
Strobe Signal
Serial /Analog Output
Serial /Analog Input
NET
030
SIO
VJI
VMI
EVI
VGB
adept
Monitor Output
Keyboard / Pointer Device
Digital Input
Digital Output
Drive signals
Encoder data
adept
User Equipment
USER EQUIPMENT
(Eg., Conveyors, Part Handlers, Sensors)

Figure 1-1. Typical AdeptVision VXL System

Controller and Vision Processor

The controller contains the logic boards, system and vision processor boards, I/O boards, and camera connector. This hardware system provides an environment for Adept's V^+ Operating System and Language that allows you to direct and monitor vision operations. The hardware/software combination is multitasking and contains everything necessary to control:

- Four physical cameras per vision system (32 virtual cameras)
- Strobe lights for two physical cameras (AdeptVision VXL provides the connection for a signal pulse for user-supplied strobe lights)
- A graphics monitor
- User-installed serial, digital, and (optionally) analog I/O devices
- User-supplied equipment such as conveyor belts (systems equipped with motion devices)

> **NOTE:** The minimum processor/memory requirement for an AdeptVision system with one vision board is one processor with 4 MB of memory. Adding memory in a single-CPU configuration will not affect vision performance. Adding an auxiliary processor (and assigning the vision processing to that CPU) could significantly increase vision performance.

Robot or Motion Device

Adept controllers may control robots or other motion devices. This manual describes vision guidance for the standard Adept robots. The principles described for these robots can be generalized to any other motion devices your system may be using.

Graphics Terminal

The graphics monitor displays all vision system input and output. The system supports multiple windows; the monitor can display output from a camera, input from other cell control equipment, and operator input and prompts. The graphics monitor is used along with the keyboard and trackball to develop vision applications. This equipment also can be set up to function as the operator interface during execution of vision applications.

User Equipment

You can communicate with the controller using serial, digital, and analog I/O. The serial channels support RS-232, RS422, and RS485 protocols which are generally used for printer output and communication with other controllers or computers.

The digital output channels are used to switch the user-supplied current to external equipment. Signaling a part feeder to place a part in the field of view is a sample digital output operation.

Digital input channels tell the controller that an event (such as a part being placed in the field of view) has occurred, and that your program should either suspend or continue execution (or take any other appropriate action).

The optional analog I/O channels allow you to read from and write to compatible analog I/O devices.

See the *Adept MV Controller User's Guide* for details on installing digital, serial, and analog I/O devices. See the *V⁺ Language Reference Guide* descriptions of IO, SIG, and SIGNAL( ) for details on programming digital I/O. See the descriptions of ATTACH, READ, GETC, WRITE, and DETACH for details on programming serial I/O. See the descriptions of AIO.IN and AIO.OUT for details on analog I/O. See the description of the utility program CONFIG_C in the *Instructions for Adept Utility Programs* for details on the configuration of digital, analog, and serial I/O.

What AdeptVision VXL Does

Quite simply, the AdeptVision VXL system looks at something and then tells you what it knows about that thing. The system has software tools that allow you to control how AdeptVision VXL looks at objects and what information it gathers about those objects. AdeptVision VXL has three primary information processing strategies:

> **NOTE:** Each of these processing strategies can be used independently or in conjunction with the other two.

- In the first strategy, boundary analysis, AdeptVision VXL looks at the boundaries of whatever is in the field of view and calculates information such as the perimeter, centroid, and area of each bounded region.
- In the second strategy, vision tools, you place ruler, window, and finder tools in the field of view, and AdeptVision VXL returns information based on what it finds with those tools.
- In the third strategy, vision model processing, AdeptVision VXL compares each bounded region in the field of view with known shapes or models you have placed in memory, and attempts to identify the region. ObjectFinder, Prototype recognition, and OCR are the options in this mode of operation.

  Image correlation is another option in this strategy. The correlation template is considered a model. However, correlation templates are not really "bounded regions" like blobs. A correlation template is an array of graylevel values recorded from the pixels in a specified are of the field of view. When a match is attempted, this array of values is compared with the graylevel values in a given search area. See "Performing Correlation Matches" on page 181 for more details.

Inspection vision systems will use the results of the various vision options to make quality, gauging, and other measurements of objects in the field of view.

Guidance vision systems will use vision options to locate and acquire items in the field of view.

Vision Basics

Throughout this manual you will be seeing the object shown in Figure 1-2. We will use this sample object to help explain the features of the AdeptVision VXL system.

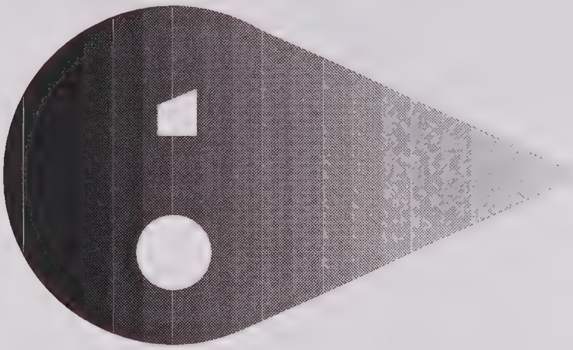


Figure 1-2. Sample Object

Pixel

The basic unit of a vision image is a pixel (picture element). It is the smallest unit of information a vision system can return to you. The number of pixels the system can process determines the system's resolution and affects the computer processing time needed to analyze an image.

A pixel can be thought of as a single cell in a matrix that the camera overlays on the field of view. The value that is placed in that cell will be a shade of gray that represents the intensity of the light reflected from the corresponding area in the field of view (grayscale vision). Figure 1-3 shows how a 22 x 16 pixel camera would see the object shown in Figure 1-2. (The dashed lines are shown for reference; they are not actually "seen" by the system.)

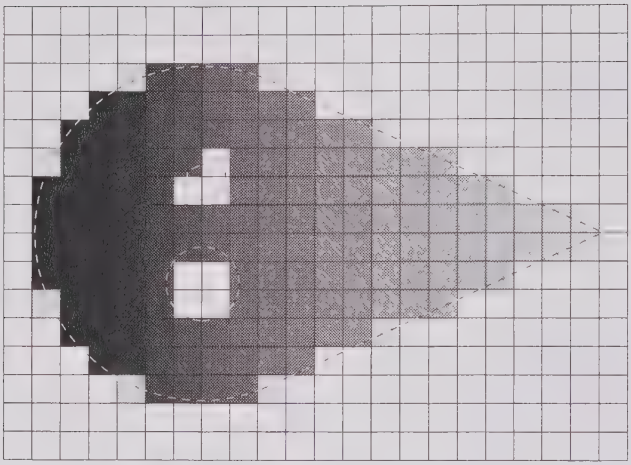


Figure 1-3. A Grayscale Image

In addition to grayscale processing, AdeptVision VXL can process image data in binary mode. In binary mode, all the cells with a value above a certain value will be seen as white and those below that value will be seen as black. **Figure 1-4** shows how the sample object would be seen in binary mode. **Chapter 8** discusses the features and uses of grayscale and binary modes in more detail.

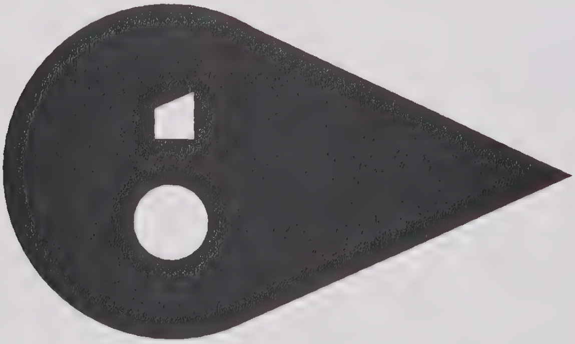


Figure 1-4. A Binary Image

The Camera Imaging Surface

Video cameras used for machine vision replace the film used in a traditional camera with a light sensitive electronic surface. When you instruct the system to acquire an image ("take a picture"), the imaging surface is "exposed" for a short time and the "exposure" is read into the vision processor. The electronic surface is actually an array of photon detectors that store a charge based on the amount of light hitting the detector. The more light that hits an individual detector, the larger the stored charge and the higher the grayscale value that is read into the vision processor. When an image is acquired, all the charges in the imaging surface are zeroed out, the surface is exposed for 1/10,000 to 1/30 of a second, and the value recorded in each cell (pixel) of the imaging surface is read into the vision processor. The resulting matrix of values is analyzed to locate edges and bounded regions. Vision tools can then be used to measure distances between edges, recognize bounded regions, and extract other information about the image.

Resolution

The number of rows and columns in the camera imaging surface, the lens focal length, and the distance of an object from the camera will determine the final resolution of whatever you are viewing. Figure 1-5 shows the relationship between focal length and viewing distance. In general, optimum resolution will come when the object of interest fills as much of the field of view as possible while still being in focus.

The image representation of our hypothetical 22 x 16 camera shows very poor resolution due to the low density of pixels. The size of the arrays in cameras supported by AdeptVision VXL typically ranges from 501 x 485 pixels to 768 x 493 pixels. Appendix D details the steps to selecting the optimum lens focal length, viewing distance, and camera imaging surface.

An important concept that is illustrated by Figure 1-5 is the relationship between a pixel's dimensions and the physical size of an object. A pixel will always have a *relative* relationship to the size of an object. It will have an *absolute* relationship only when you fix your viewing distance and lens focal length and then calibrate the vision system. The calibration process establishes an absolute relationship between a pixel and the actual dimensions of the field of view. See Chapter 4 for an overview of the calibration procedure.

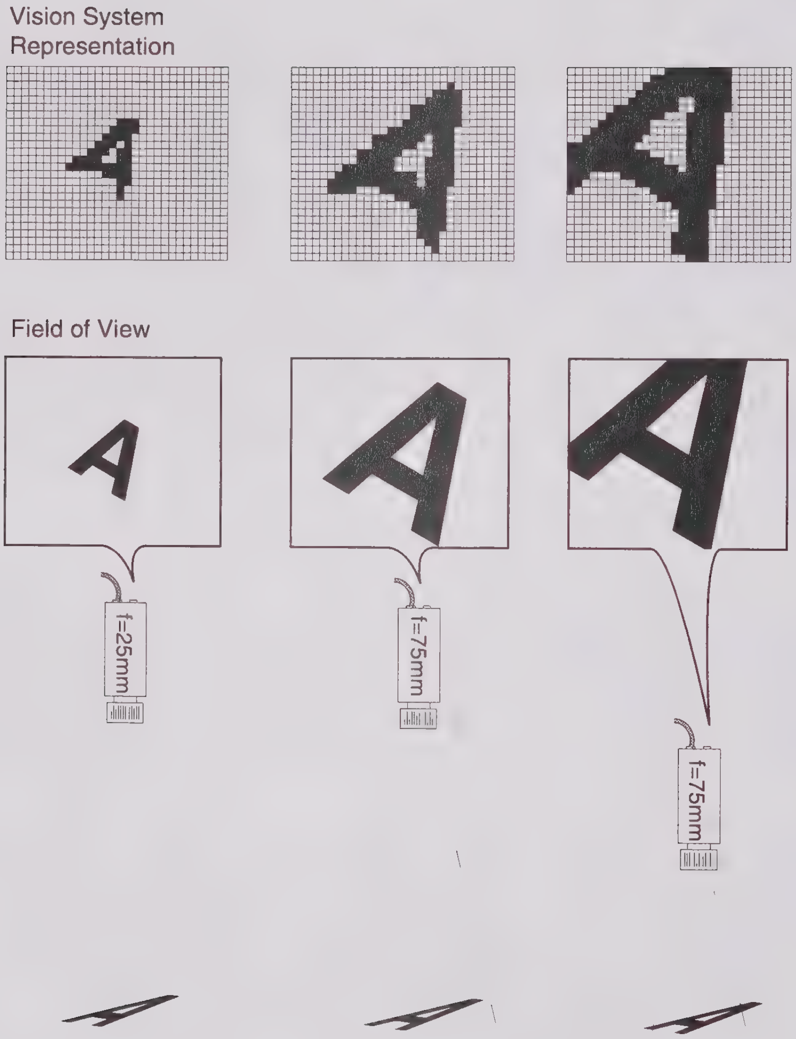

Vision System
Representation
Field of View
f=25mm
f=75mm
f=75mm

Figure 1-5. Resolution Factors

Summary of Software Tools

This section gives a brief overview of the vision tools provided by AdeptVision VXL. These tools are detailed in Chapters 9, 10, and 11.

Boundary Analysis

Boundary analysis locates objects in the field of view and returns information about those objects' sizes, locations, perimeters, etc. Boundary analysis locates objects by looking for bounded areas (a contiguous area of light or dark pixels in the binary image). These bounded areas are often called "blobs".

Rulers

Rulers are inspection tools you place in the vision image that return information based on the values found in the pixels the ruler crosses. Linear rulers return distances between features of an object based on intensity changes (edges) in the field of view. Arc rulers return the angular distance between object features. You can set the length, angle, and position of these rulers. Rulers work with both grayscale and binary images. You can place multiple rulers in the field of view, inspect multiple objects, and examine the relationship between multiple objects.

Inspection Windows

Inspection windows provide a quick way of obtaining basic graylevel, binary, or edge statistics about specific areas of an image.

Finder Tools

These tools allow you to find points, lines, and arcs in an image. The data returned from finder tools may provide all the information you need about an object, or it may provide the basis to perform other inspections.

ObjectFinder

The ObjectFinder has been added to AdeptVision VXL for V$^+$ version 12.1. This tool's functionality is similar to prototype recognition. However, the ObjectFinder uses grayscale edge-based features. See Appendix C for more details on the ObjectFinder.

A user-interface for the ObjectFinder tool is provided in VisionWare. It is highly recommended that users interested in this tool access it through VisionWare, as this interface provides the greatest compatibility and ease of use. See the *VisionWare User's Guide* for more details.

Processing Windows

In Chapter 8 you will learn the difference between processed and unprocessed images. In many cases, you can speed up your applications by operating on unprocessed images or by processing only a limited portion of the field of view. Processing windows (see Chapter 10) allow you to process a limited area of the field of view. (In contrast to inspection windows, processing windows do not return any data about the image: They merely process a portion of an image for use by other vision tools.)

Modeling

Modeling allows you to store models of different objects in vision system memory and then compare these models with objects in the field of view. The system will tell you if an object in the field of view matches a model in vision system memory, how close the match is, and where the object is in the field of view.

Overview of Guidance Vision

AdeptVision makes use of the tools just described both to inspect objects and to provide information to the motion device about an object's location.

Frames

All robot motion is based on frames of reference and location variables. Location variables uniquely identify a point within a Cartesian space and the orientation of the robot tool at that point. All robots and motion devices will have a primary reference frame. On Adept SCARA robots the primary reference frame is centered at the base of the robot with the Z axis pointing straight up, the X axis going front to back, and the Y axis going left to right.

The V^+ language provides several options for creating new frames of reference that are relative to this primary reference frame. Relative reference frames can also be created with respect to other relative reference frames. It is these relative reference frames that allow the vision system to guide robot motions.

Depending on the camera mounting location, different relative reference frames will be used to relate the camera field of view to the robot work space. Chapters 13 and 14 give the details of creating and using these frames.

Things to Consider When Designing Your Workcell

While designing your workcell, keep in mind the following considerations:

Consistent Environment

For your results to be consistent and predictable, the environment in which you operate the vision system must be as consistent and predictable as possible.

Avoid major changes in temperature and humidity. Mount the cameras so that a constant distance is maintained from the camera to the object.

Isolate the cameras as much as possible from sources of vibration.

Ease of Maintenance

Periodic maintenance and repair of your system will be necessary. Design your workcell to allow access to all the vision system components as well as any other equipment you may have installed.

Safety

If there is any moving equipment, such as part feeders or conveyor belts, design the workcell so that all normal operations can take place without the operator coming into dangerous contact with the moving equipment.

Lighting

Consistent lighting is critical to accurate, predictable vision operations. Appendix E lists the advantages and disadvantages of various lighting systems. Before you select and install a lighting system, experiment with different lighting setups and see which one provides you with the most consistent results. These results should be checked throughout the duration of the shift in which the system will be operated to see how changes in ambient light affect the system.

Creating an optimum and consistent lighting environment when you design your workcell will save a great deal of trouble later!

Installation 2

Setting up the Hardware 44

  Installing the Controller 44
  Attaching Cameras and Strobes 44
    Strobe Compatibility 45
  Cameras Supported by AdeptVision VXL 45
    Panasonic GP-MF602 45
    Panasonic GP-MF702 45
    Pulnix TM-1001 46
    Sony XC-77 46
  Mounting Cameras 47

Setting up the Software 48

System Memory 49

Setting up the Hardware

Your vision system includes the following items:

- An Adept MV controller equipped with:
    - A System Processor Board
    - Graphics Processor Board
    - Vision Processor Board (VIS) or Enhanced Vision Interface Board (EVI)
    - V^+ Operating System and Language (Version 12.0 or later) with the Vision option
- Adept Utility Programs Disk
- High-resolution color monitor
- AT compatible keyboard and pointing device
- One or more cameras

You may be installing the following options:

- Camera lenses, extension tubes
- Strobe lights or other area lighting
- Optical filters
- Camera mounting hardware
- Robot or motion device

Installing the Controller

Your controller should be set up and configured before you install the peripheral vision system equipment. See *Adept MV Controller User's Guide* for details on setting up the controller. This guide also shows where to connect the monitor, keyboard, and pointing device to the controller.

If you are using digital I/O, pay particular attention to the controller user's guide's instructions on installing and configuring digital I/O in your workcell.

Attaching Cameras and Strobes

The *Adept MV Controller User's Guide* shows how to connect cameras and strobes and to set any hardware options required by the various cameras and strobes.

Appendix M lists several manufacturers that supply strobe lighting (and general lighting) that is compatible with AdeptVision systems.

Strobe Compatibility

Adept's strobe signal is TTL compatible with a duration of 120 µsec and an output of 80 - 120 mA (positive going pulse). The strobe signal is normally set "active high" but can be configured using the DEVICE instruction (see Appendix J). Strobe lights have a latency between signal detection and flash. This latency combined with the flash duration should not exceed 100 µsec.

Cameras Supported by AdeptVision VXL

The cameras listed here can be used with AdeptVision VXL. Not all features of all cameras are supported by AdeptVision VXL. The following highlights the main features of each camera:

Panasonic GP-MF602

This is a black and white industrial CCD camera with a resolution of 768 x 494 pixels. It has an asynchronous frame reset mode and electronic shutter trigger mode.

Nonshuttered cameras require about 1/30 of a second to acquire an image. This speed is too slow to acquire unblurred images of moving parts. Shuttered cameras have shutter speeds of 1/1,000 to 1/10,000 sec., allowing them to acquire clear images of moving parts without the use of strobe lighting. With shuttered cameras, the strobe signal is used to latch the external encoders of motion devices simultaneously with image acquisition. Since the timing of a strobe signal used to record encoder positions is different from the timing for a strobe light, cameras used in shuttered mode cannot be used with strobe lights.

When you are using a shuttered camera, images must be acquired in field-acquire mode.

Panasonic GP-MF702

This camera has a resolution of 649 x 491 pixels. This camera can be set up to use the "pixel clock" output of the vision board. This camera uses an MOS array rather than a CCD array for the imaging element. MOS arrays shift data from the imaging element to the vision processor differently from CCD array cameras. Therefore, asynchronous strobe operation will not work.

Pulnix TM-1001

This is a "large-format" (1024 x 1024 pixels) camera that is supported by the EVI board. When you set your system for large frame buffers, this camera model (#6) will be the default for all virtual cameras, rather than the normal camera model (#0).

You can install up to two of these cameras per EVI board. The board's AM-VS module must be configured differently in order to work with the TM-1001. See the *Adept MV Controller User's Guide* for EVI board installation details.

The TM-1001 can operate in an asynchronous acquire mode that allows it to acquire and store a frame buffer upon receiving a VINIT signal. The VINIT signal is transmitted on the BNC connector of a custom cable pair. See Appendix I for details on configuring the Pulnix TM-1001 camera.

> **NOTE:** The Pulnix TM-1001 camera and cables are custom Adept configurations. The camera must be ordered directly from Pulnix; the cables must be ordered directly from Intercon. Please contact the Adept Application Questions hotline or see the Adept on Demand Web Page for part numbers and ordering information.

Sony XC-77

This is an electronically shuttered camera with a resolution of 768 x 493 pixels. See the description of the Panasonic GP-CD 40 camera for additional details on shuttered cameras. This camera can be set to operate in standard, nonshuttered mode.

The Sony XC-77 provides both synchronous and asynchronous shuttered capability. When used in asynchronous mode, the maximum number of images that can be acquired per second is 30 (60 is the maximum in synchronous mode).

> **NOTE:** When a camera is used in pixel-clocked, asynchronous, or shuttered mode, the camera must be properly set up to operate in the selected mode. See the camera instructions for details on setting up the camera for different operating modes.

The following cameras are also compatible with AdeptVision VXL:

- Hitachi KP-M1
- Panasonic GP-CD 40
- Panasonic GP-MF502
- Panasonic GP-MF552

Contact your Adept salesperson for details on the cameras sold directly by Adept. Contact Adept Applications for current details on camera compatibility.

Mounting Cameras

Mount your cameras rigidly and dampened from vibration. Consistent vision results depend on cameras that stay a constant distance from the objects being viewed. Cameras that can skew, change position on their mounts, or lose focus due to vibration or contact will cause problems over the life of your application.

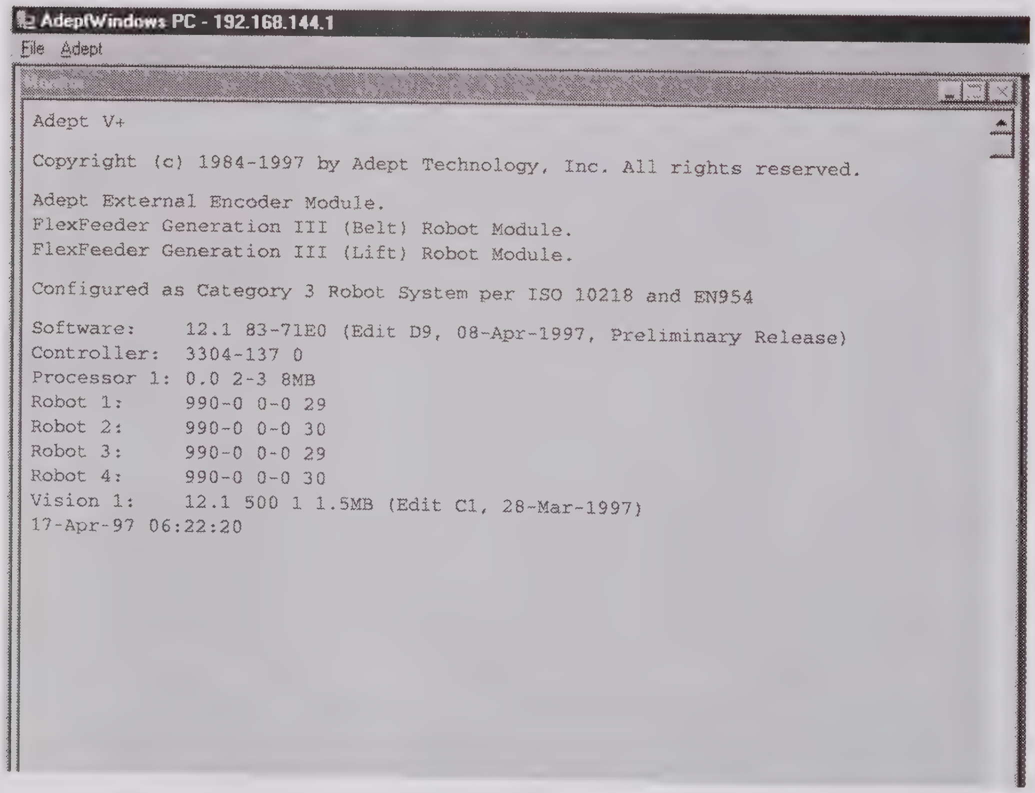
Appendix M lists several suppliers of camera and lighting mounting hardware.

Setting up the Software

Your vision system leaves the Adept factory with the operating system and vision software installed on a floppy disk. (If your system has a hard drive, the operating system and vision software are also installed on the hard drive [C:].)

To boot the system and bring up the vision monitor, turn on the monitor, place the system disk in drive A, and turn on the controller. If the hard disk option is installed, just turn on the monitor and controller.

After power is turned on, the system will go through a series of self-tests and then load the operating system. When the load procedure is complete, you will see a screen similar to Figure 2-1 showing copyright information and the ID lines. The ID lines contain coded information about the configuration of your system. See the ID command in the *V+ Language Reference Guide* for details on the meaning of these lines.



```
Adept V+

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Adept External Encoder Module.
FlexFeeder Generation III (Belt) Robot Module.
FlexFeeder Generation III (Lift) Robot Module.

Configured as Category 3 Robot System per ISO 10218 and EN954

Software:     12.1 83-71E0 (Edit D9, 08-Apr-1997, Preliminary Release)
Controller:   3304-137 0
Processor 1:  0.0 2-3 8MB
Robot  1:     990-0 0-0 29
Robot  2:     990-0 0-0 30
Robot  3:     990-0 0-0 29
Robot  4:     990-0 0-0 30
Vision 1:     12.1 500 1 1.5MB (Edit C1, 28-Mar-1997)
17-Apr-97 06:22:20
```

Figure 2-1. Initial Screen

When your monitor looks like **Figure 2-1**, you are ready to begin vision operations and to load vision application programs. See the *V^+ Operating System User's Guide* for details on installing application software.

System Memory

The amount of system memory allocated for the vision system software is 1.5Mb (this value was increased from previous V^+ versions). This value is stored with the configuration data for the controller. The memory allocation was increased to accommodate the ObjectFinder tool and to support the Enhanced Vision Interface (EVI) module.

The default value can be increased (using the CONFIG_C utility) to provide more room for correlation templates, OCR fonts, and prototypes.

> **NOTE:** The default system memory value must be increased if any significant adjustments are made to the fixed memory allocations.

See Appendix K for more details on memory allocation. See the *Instructions for Adept Utility Programs* for details on the CONFIG_C utility.

Getting Started 3

V+ Syntax Conventions 52

Virtual Cameras 53

  What Is a Virtual Camera? 53
  How Are Camera Numbers Assigned? 54
  Why Use Virtual Cameras? 54

Motion Devices and Calibration 54

  Calibration 54
    Motion Device Calibration 55
    Start-up Calibration 55
    Camera Calibration 55
  The Vision Transformation 55
    Fixed-Mount Camera Transformation 55
    Robot-Mounted Camera Transformation 56

Loading Vision Calibration Data 57

V+ Syntax Conventions

This manual details V+ keywords (monitor commands, functions, and program instructions). These operations are presented using the following syntax conventions (see **Figure 3-1**):

- Keywords are typed in capital letters and should be typed exactly as they are shown. For example, **`LOAD`** should be typed exactly as it appears.
- Arguments are shown in lowercase letters and should be replaced with arguments you provide. For example, **`drive`** should be replaced with a drive letter you choose.
- Keywords and arguments shown in **`bold type`** are required; those shown in `regular type` are optional. If you omit an optional argument, the system will assume a default value.

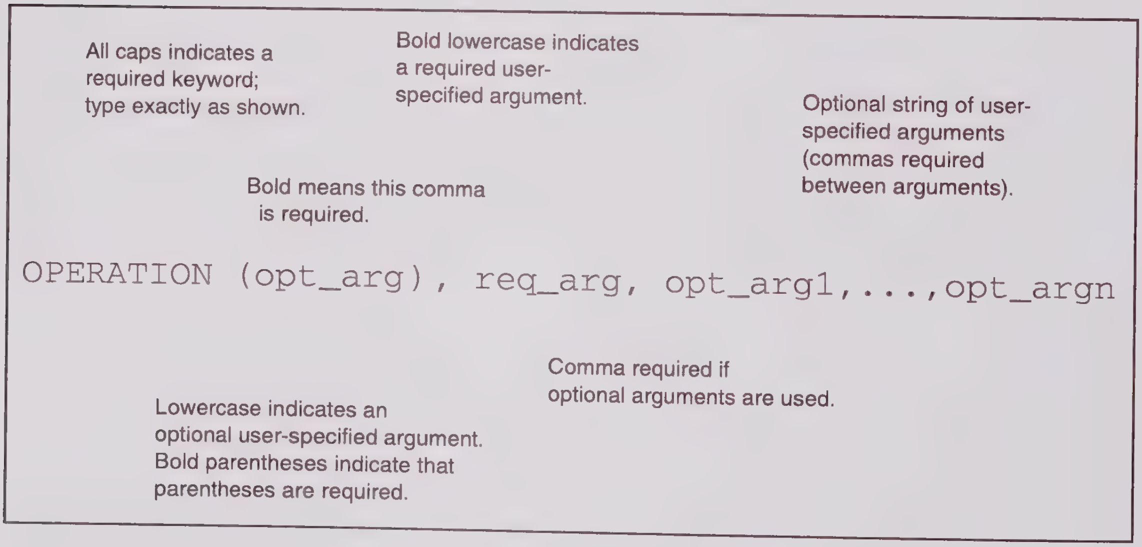

All caps indicates a required keyword; type exactly as shown.
Bold lowercase indicates a required user-specified argument.
Optional string of user-specified arguments (commas required between arguments).
Bold means this comma is required.
OPERATION (opt_arg), req_arg, opt_arg1,...,opt_argn
Comma required if optional arguments are used.
Lowercase indicates an optional user-specified argument. Bold parentheses indicate that parentheses are required.

Figure 3-1. Sample Operation

NOTE: For the sake of simplicity, the operations detailed in this manual do not list all available options. See the *V+ Language Reference Guide* and the *AdeptVision Reference Guide* for a complete description of all keywords.

Remember, AdeptVision VXL supplies an extension to the basic V+ programming language. The basic language elements such as control structures, mathematical functions, etc., are detailed in the *V+ Language Reference Guide* and the *V+ Language User's Guide.*

Virtual Cameras

AdeptVision VXL allows you to establish several virtual cameras for each of your physical cameras (as long as the total number of virtual cameras does not exceed 32). One of the most important things you will learn in the next three chapters is how to control what a camera sees. You may find that you want to take several pictures of an object with each picture looking at the object in a different way or from a different distance. Virtual cameras allow you to do this. For example, you might want your first picture of an object to look at the perimeter shape and your second picture to look at interior features of the object. By establishing two virtual cameras for the physical camera looking at the object, you can take both types of pictures of the object.

What Is a Virtual Camera?

The controller allows you to attach four different cameras to each vision processor. These cameras are the "physical" cameras. Associated with each physical camera will be one or more virtual cameras. A virtual camera is a single set of switches and parameters, calibration data, and a vision queue (see Figure 3-2). Switches and parameters are introduced in the next two chapters. The vision queue is introduced in Chapter 9. Calibration is discussed in the next section. A physical camera can have up to 32 virtual cameras associated with it, but the total number of virtual cameras associated with *all* physical cameras cannot exceed 32. Each physical camera must have at least one virtual camera associated with it. If you have 4 physical cameras—camera 1 could have eight virtual cameras, camera 2 could have sixteen virtual cameras, camera 3 could have five virtual cameras, and camera 4 could have three virtual cameras. Or they could have any combination of virtual cameras that add up to 32 or less.

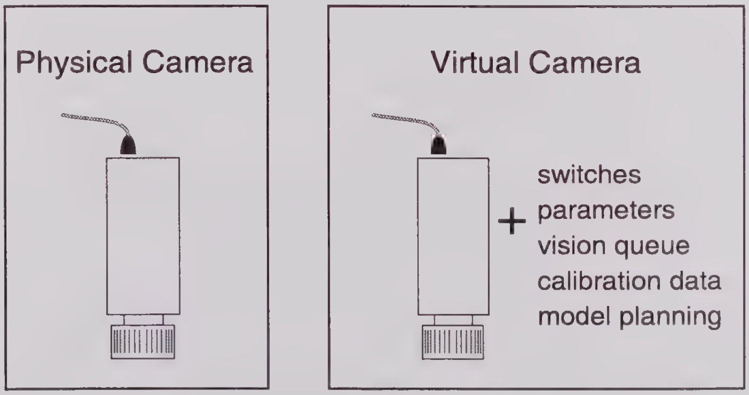


Figure 3-2. Physical/Virtual Camera Relationship

How Are Camera Numbers Assigned?

The physical camera number is determined by the port the camera is plugged into on the vision processor (see *Adept MV Controller User's Guide*). The virtual camera number (and the physical camera associated with it) is determined during camera calibration or when calibration data is loaded. One of the first questions asked during camera calibration is what virtual camera number you want associated with the physical camera you are calibrating. Your answer to this question determines which virtual camera is being calibrated and which physical camera it will be associated with.

Why Use Virtual Cameras?

Switches and parameters can be set for an individual virtual camera. Calibration data and prototype groups can also be defined for individual virtual cameras. Virtual cameras allow you to use the same physical camera to look at the same image using different combinations of calibration, prototypes, switches, and parameters simply by specifying different virtual cameras.

For example, you might be inspecting different areas of an object, each of which requires its own switch/parameter settings. Or you might be presenting two (or more) different objects to the same camera for inspection. If these objects are different distances from the camera (but still in focus), you will need different camera calibration data for each object. Since camera calibration is established for each virtual camera, you could use different virtual cameras calibrated for the different distances to inspect the objects.

Unless noted, this manual assumes your system has only one camera and that virtual camera 1 has been assigned to it. Therefore, all references to a camera mean *virtual and physical camera 1*.

Motion Devices and Calibration

For systems with motion devices, three different types of calibration must be completed before an AdeptVision VXL system can be used. In addition, a vision transformation will be required.

Calibration

This section describes the three types of required calibration: motion device calibration, start-up calibration, and camera calibration.

Motion Device Calibration

This calibration establishes the relationship between the robot's encoders and the actual space the robot works in. On Adept robots, this calibration is performed at the factory and will not need to be repeated unless an encoder is replaced or other major repair is performed. For other motion devices, this calibration is performed with the AdeptMotion VME utility SPEC.V2. See the *Instructions for Adept Utility Programs* manual for details.

Start-up Calibration

When a motion device and its controller are first turned on, the device must relate its current location to the motion device calibration data. This procedure is accomplished by entering the commands:

```
ENABLE POWER
CALIBRATE
```

See the robot user's guide or the *AdeptMotion VME Developer's Guide* for more details.

Camera Calibration

The relationship between the camera field of view and the motion device must be established before the vision system can be used to locate objects for the motion device. See Chapter 4 for an details on the camera calibration procedure.

The Vision Transformation

Guided vision is essentially the process of putting together several pieces of information to create a transformation. A transformation defines a location a motion device can move to. You must be familiar with the Adept transformation value before you can program motion device applications. See the *V⁺ Language User's Guide* and the *V⁺ Language Reference Guide*. The next two sections summarize this transformation for fixed-mount and for robot-arm-mounted cameras. Chapter 13 presents detailed information.

Fixed-Mount Camera Transformation

The transformation value to pick up an object using a fixed-mount camera has the following possible elements:

- The location, in world coordinates, of the origin of the vision reference frame. This location is created by the camera calibration routine and stored in the "to.cam[ ]" array.
- The offset and rotation of the part relative to the vision reference frame. These values are calculated using different vision tools (described in Chapters 9 - 11).

- The offset from the center of the quill flange to the center of the actual gripping location ("TOOL transformation"). See the description of the TOOL program instruction in the *V+ Language Reference Guide* for details.

Robot-Mounted Camera Transformation

The transformation value to pick up an object using an arm-mount camera has the following elements:

- The offset, in tool coordinates, from the origin of the vision reference frame to a location on the robot that is fixed relative to the camera (this location varies depending on the joint the camera is mounted on). This transformation is created by the camera calibration routine and is stored in the "to.cam[ ]" array.
- The offset and rotation of the part relative to the vision reference frame. These values are calculated using different vision tools (described in Chapters 9 - 11).
- The offset from the center of the quill flange to the center of the actual gripping location ("TOOL transformation"). See the description of the TOOL program instruction in the *V+ Language Reference Guide* for details.
- The current position of the robot joint the camera was calibrated to. The robot joint—that the camera calibration transformation is based on—moves. Therefore, the current position of the robot joint must be recalculated each time a picture is taken at a new location. This is a simple calculation that is described in Chapter 13.

The next four chapters will describe the tools and options available to calculate the necessary parts of a vision transformation.

Loading Vision Calibration Data

After you have turned off the controller or zeroed system memory, calibration data is no longer available and will have to be reloaded. There are two ways of loading calibration data to system memory from a disk file. The first is to use the camera calibration program. The second is to call the program "load.area( )" from your application program. See Chapter 5 for details on using ADV_CAL to load calibration data.

Loading calibration data by calling "load.area( )" from an application program is shown in the programming example in Chapter 12 and described in the *Instructions for Adept Utility Programs* manual.

If you are using VisionWare or MotionWare with vision, the calibration data is automatically loaded when VisionWare or MotionWare is started.

> **NOTE:** In order for loaded calibration data to be valid, the physical camera associated with the virtual camera must be in the same location and have the same lens settings as when it was calibrated. If this is not the case, the system will still return data, but the data may not be valid.

Vision Calibration Overview

4

Compatibility 60
Why Calibrate a Camera? 60
    Millimeter-to-Pixel Ratio 60
        When Do I Need the Millimeter-to-Pixel Ratio? 62
    Perspective Distortion Corrections 63
        When Do I Need the Perspective Distortion Corrections? . 63
    Camera-to-Robot Transformation 64
        Fixed-Mount Cameras 64
        Robot-Mounted Cameras 64
Before You Start Calibrating Your Cameras 65
    What You Need 65
        Calibration Object 65
    What You Need to Do 67
    Things to Remember (Important Stuff) 67
        When to Recalibrate the Camera 67
        Virtual Cameras 68
        Resolution, Accuracy, and Repeatability 68

Compatibility

This calibration procedure is for use with V^+ systems equipped with the AdeptVision VXL software and hardware options. The system version must be 12.0 or later.

This procedure should not be used with earlier versions of the program.

CAUTION: Application programs that use the calibration results from the Advanced Camera Calibration program *must* use a "grip" transformation when moving to a location determined from a vision image. Furthermore, any existing grip transformation will need to be redefined after calibration with this program.

Why Calibrate a Camera?

Before AdeptVision VXL can return meaningful results, the system must know basic information about your particular installation. The camera calibration program generates this information and stores it in a form usable by AdeptVision VXL. There are three primary pieces of information determined by the calibration program:

- The millimeter-to-pixel ratio
- Correction factors for perspective distortion
- The camera-to-robot transformation

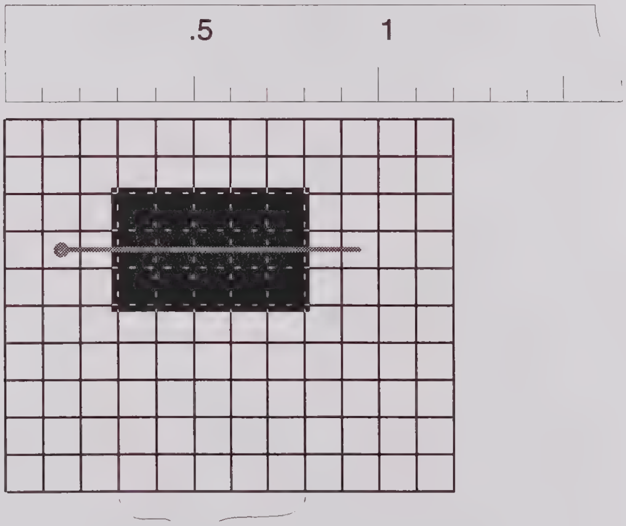
Depending on what you are doing with your vision system, you may not need all of these elements. The following sections describe what each element is and why you would need it.

Millimeter-to-Pixel Ratio

When an image is acquired by AdeptVision, data that describes the scene is stored in a matrix. You can think of this matrix as a piece of graph paper that is laid over the scene. In each square of the graph paper is written a value representing the intensity of light covered by the area. AdeptVision stores intensity values two ways: as a graylevel value representing the relative intensity of the area covered, and as a thresholded binary value. Graylevel values range from 0 to 127 that represent the intensity gradient of light being received by the camera. Binary values are either black or white. Each graylevel value is compared to a specified threshold value. All areas exceeding the value are considered white, and all other areas are considered black. The area of each square of the graph paper is referred to as a "pixel".

When vision tools such as rulers or finders are placed in the image, they look for edges based on the graylevel or binary data. Graylevel edges are found when the intensity change from one region of pixels to another exceeds a specified value. In the binary image, edges are found when neighboring pixels change from black to white.

In order to return distance measurements, the system must know how many pixels it takes to cover one millimeter of the image. This is the millimeter-to-pixel ratio. If the camera calibration program returns a millimeter-to-pixel ratio of .1, it means that 10 pixels will cover one millimeter of the image. This information allows tools that measure distances between edges to return measurements in real-world millimeters. Figure 4-1 shows how a ruler tool would measure a small square. In this example, a binary ruler finds two edges that are 5 pixels apart. The camera calibration program has calculated a millimeter-to-pixel ratio of 0.1. Therefore, the calculated width of the square is 0.5 millimeters.



The ruler detects edges at these 2 points.
The millimeter-to-pixel ratio has been calculated as 0.1. Since there are 5 pixels between the 2 edges, the distance measured is .5 millimeters (5*0.1).

Figure 4-1. Millimeter-to-Pixel Ratio

Notice that in the binary image, the accuracy of measurement is determined by the area covered by one pixel. The object being measured is actually slightly larger than five pixels. However, binary tools can make measurements only at pixel boundaries, so 0.5 is the most accurate measurement that can be made in this example. If greater accuracy is needed, a smaller field of view or higher resolution camera will be needed. (This will place more pixels over a given area.)

> **NOTE:** The algorithm used by *grayscale* tools looks at intensity changes in a neighborhood of pixels. This strategy allows potential subpixel accuracy.

When Do I Need the Millimeter-to-Pixel Ratio?

The following situations *require* a calculated millimeter-to-pixel ratio:

- Inspections that return absolute distance measurements
  These include distance measurements returned by VFEATURE and by VRULERI tools.
- Inspections that calculate areas or perimeters
  These include area and perimeter measurements returned by VFEATURE and by VWINDOWB and VFIND.LINE tools.
- Inspections that return Cartesian values used in guidance vision
  These include Cartesian values returned by VFEATURE and VLOCATE and from the VFIND.LINE, VFIND.POINT, VFIND.ARC, and VWINDOWB tools.
- Inspections where distances are being measured or Cartesian values are being compared from objects found by different cameras

The following situations *do not* require a calculated millimeter-to-pixel ratio:

- Inspections that return grayscale or binary pixel statistics
  These include the average, minimum, maximum, and standard deviation of graylevel values and the binary pixel counts from VWINDOWI tools.
- Inspections that return angular values
  These include angular measurements returned by VFEATURE and by VFIND.LINE tools.

  > **NOTE:** Accurate distance measurements from these tools require a calculated millimeter-to-pixel ratio.

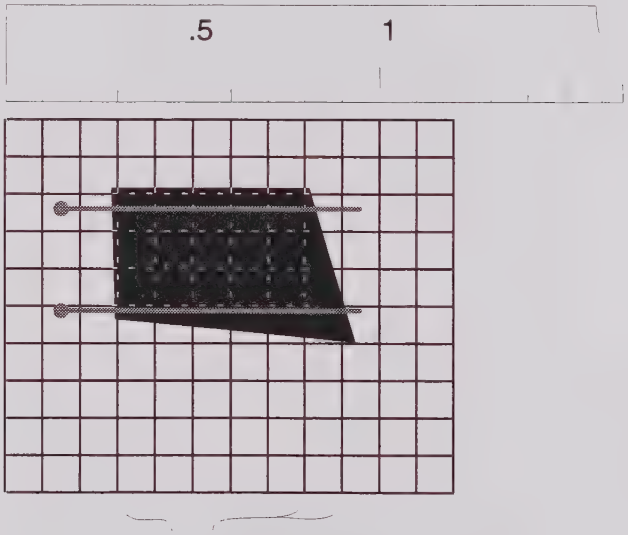
- Inspections that require only relative measurements
  If a virtual camera does not have a calculated camera calibration, a default millimeter-to-pixel ratio of 1.0 is used. Relative measurements can be made based on this default calibration.

  > **NOTE:** Relative measurements based on the default calibration can be compared only from one camera.

Perspective Distortion Corrections

In order for a camera to see an object in its correct aspect ratio, the object must be perfectly parallel to the camera imaging element. Otherwise, objects will appear distorted, and measurements will not be accurate. If the square shown in Figure 4-1 was not parallel to the camera imaging element when the image was acquired, the image might look like Figure 4-2. This distortion is similar to looking down parallel railroad tracks that appear to converge in the distance.

Notice that the two rulers in Figure 4-2 will return different widths for the same square.



The rulers detect edges at these 3 points.
One ruler calculates a width of 0.5 millimeters,
the other calculates a width of 0.6 millimeters.

Figure 4-2. Perspective Distortion

During the calibration process, a matrix of transformation elements is defined that will correct for perspective distortion. See Appendix C of the *AdeptVision Reference Guide* for details on the matrix.

When Do I Need the Perspective Distortion Corrections?

The perspective distortion corrections should be used whenever you cannot align the image surface with the camera imaging element and:

- You are using tools that return distance, angular, or Cartesian values
- You are using the system for guidance vision

Camera-to-Robot Transformation

In order to use camera data to acquire or place objects, you must use the calibration program to calculate a transformation that relates the camera field of view to the robot. There are two classes of transformations: fixed-mounted camera and robot-mounted camera.

Fixed-Mount Cameras

There are three general methods of mounting fixed cameras:

- Camera mounted in the robot work envelope
- Camera mounted upstream of the robot, viewing an encoder-equipped conveyor belt
- Camera mounted on a robot that always takes pictures in the same location

When a fixed-mount camera is calibrated, the transformation generated relates a corner of the field of view to the origin of the world coordinate frame of the robot. Using this transformation along with one that defines an object's location within the field of view, the robot can pick up or place objects.

Robot-Mounted Cameras

Cameras can be mounted in different locations on a robot. Since the camera mounting location will change as the robot moves, there is not a fixed relationship between the camera and the robot world coordinate frame (as there is with a fixed-mount camera). This means that the camera calibration transformation will be different. The robot mounted camera transformation relates the camera to a location on the robot. The transformation is calculated with the robot joints between the camera and the robot gripper in a known state (normally fully retracted or rotated 0°).

Each time the robot takes a picture at a new location, the current state of these "downstream" joints is computed and the transformation from the current camera location and the robot world coordinate system is calculated. The location of the part(s) within the field of view can then be determined so that the part(s) can be picked up.

Before You Start Calibrating Your Cameras

What You Need

- Adept Utility Programs diskette, which contains the following files:

  ADV_CAL.V2—the Advanced Camera Calibration program

  ADV_USER.V2—a subroutine that can be called by a user-written application program to take a picture with a calibrated camera, locate a desired object in the image, and determine the location (in the robot coordinate system) of the object.

- An Adept MV controller with the AdeptVision VXL option
- Camera(s) and cable from the camera(s) to the controller
- Camera lenses
- Calibration object (described below)

The following items are needed for the indicated camera calibration procedures:

- Manual control pendant (for camera-to-robot calibrations only)
- Calibration pointer (for some camera-to-robot calibration methods)

Calibration Object

The calibration procedures make use of a "calibration object" to relate the vision image to the actual physical scene viewed by the camera. Depending on the specific calibration method you use, one or more of the following objects can be used as the calibration object.

For camera-only calibrations—the Adept Calibration Sheet supplied with the system. (This sheet is a series of nested squares.)

For camera-only calibrations—a thin, flat square or disk of *known dimensions* (the color *must* contrast with the surrounding work area).

For robot-related calibrations—a rigid, thin disk with a color that contrasts with the surrounding work area.

> Adept provides two sizes of calibration disks. When deciding which calibration disk to use (or how large to make one), try to keep the image size of the disk between 1/10 and 1/3 the height of the vision window.

If you make your own disks, consider the following design details, which will improve the accuracy of the calibration results:

a. The thinned edge of the disk reduces the possibility of the disk casting a shadow on the work surface. Such a shadow would be seen by the vision system as part of the disk itself, which could distort the calibration data.

b. The conical hole in the center of the disk aids the process of centering the calibration pointer over the disk. Also, the size of the hole is matched to the ball on the end of the Adept calibration pointer, so that the pointer will be at the height of the work surface when the pointer is seated in the hole.

See **Appendix G** for details on calibration target dimensions.

If a vacuum gripper is being used, the disk must be larger than the opening of the vacuum gripper. Of course, the disk should be fairly nonporous so that the vacuum gripper will be able to pick it up. You can use one of the calibration disks provided by Adept if you cover the center hole with a piece of tape.

For robot-related calibrations—a contrasting dot drawn on a rigid, flat surface.

The background color of the surface must blend in with the surrounding work area, or the surface must be large enough to fill the vision window. The dot need not be round, but should be a simple shape. When deciding how large a dot to draw, plan to have the image size of the dot between 1/10 and 1/3 the height of the vision window.

If a vacuum gripper is being used, the flat surface (but not necessarily the dot) must be larger than the opening of the vacuum gripper. Of course, the surface should be fairly nonporous so that the vacuum gripper will be able to pick it up.

When a disk or dot is used in the calibration process, its location in a camera image is based on the object's centroid. However, you have the option of defining a routine to refine the location. This routine must be named "ac.refine.vloc( )" and can use tools such as VFIND.ARC to refine the locations that the main program will use to compute the calibration. See the programs **adv.cam.user( )** and **adv.tr.point( )** in **Appendix H** for the calling sequences and sample routines.

The methods for determining camera-to-robot calibration all rely on the camera seeing a contrasting object. In most situations, that can be a disk, a round dot, or any other simple shape. This manual uses the term "disk" to refer to any type of object.

What You Need to Do

Below is the list of things you need to do before beginning the calibration procedures:

- Have the Adept MV controller installed and running
- In robot systems, have the robot ready to make commanded moves (high power is enabled and start-up robot calibration has been performed)
- Calculate the required accuracy of your application and select cameras, lenses, and extension tubes that provide a field-of-view size that guarantees the required accuracy (see **Appendix D** for details)
- Have the cameras rigidly mounted in their permanent locations (if the camera is mounted on the robot, it must be mounted so that it will be moved in a plane parallel to the work surface)
- If a camera is mounted upstream on a conveyor belt, have the conveyor installed and calibrated
- If high-accuracy mapping has been done, load the HPS map
- Review the various calibration options and make sure you have any other items required by the selected option

Things to Remember (Important Stuff)

When to Recalibrate the Camera

If the size of the field of view changes, the camera should be recalibrated.

Camera calibration is very sensitive to the size of the field of view. The following actions will change the size of the field of view:

- Changing cameras or lenses, changing lens focus, or adding or removing extension tubes
- Changing the lens aperture setting (f-stop)
- Changing the distance from the camera to the work surface

Once calibration is complete, Adept recommends that you secure your lens's focusing and aperture setting rings so they cannot be tampered with and move as a result of vibration. This is especially true of robot-mounted cameras. In some cases, simply taping the lens will work. In other cases, more elaborate clamps or set screws will be needed.

If the camera mounting position is changed, the camera should be recalibrated.

The transformation used by guidance vision cameras is sensitive to the camera location, either with respect to the robot world coordinate frame for fixed cameras or with respect to the joint the camera is mounted on for robot-mounted cameras.

Virtual Cameras

Camera calibration is calculated and stored for virtual, not physical, camera numbers. When you calibrate a camera, virtual and physical camera are paired.

If a camera views work surfaces that have different camera-to-surface distances (for example, a robot-mounted camera that is moved to view areas of the workcell with different heights), a different camera calibration should be used for each camera-to-surface distance. This is done by calibrating a different *virtual* camera for each camera-to-surface distance.

See Chapter 5 and Chapter 6 for additional details on calibrating virtual cameras. See Chapter 8 for information on using virtual cameras.

Resolution, Accuracy, and Repeatability

Vision system resolution is a function of the size of the field of view—vision systems do not have any intrinsic resolution specification. The smaller the field of view, the higher the system resolution. The larger the field of view, the lower the resolution. When designing your system, you must ensure a field-of-view size that will meet your minimum resolution requirements.

The various elements of the vision system influence the accuracy and repeatability of results returned at a given resolution. If you have selected components and viewing distance that give you .001 millimeter resolution, but those components introduced 5% error, you will not accurately measure to a resolution of .001 millimeters. If the quality of lighting at the work surface changes and objects appear different to the vision system, you will not make repeatable measurements.

The system components that affect accuracy and repeatability are:

- The quality of the camera and camera imaging element
- The quality of the optics
- The quality of the camera cabling
- The quality and consistency of lighting

After selecting, installing, and calibrating a vision system, empirical testing still must be done to prove that your vision setup is measuring to the accuracy and repeatability required.

For camera-only calibration, you can use the precision calibration sheet provided by Adept, or you can construct your own target. The calibration target is placed on the work surface in the camera field of view.

For camera-to-robot calibration, automatic procedures are provided for several of the more common camera mountings (such as upward-looking or on link #2 of an Adept SCARA robot). In addition, there are semiautomatic procedures for the general cases of arbitrarily mounted fixed cameras and robot-mounted cameras on an Adept-supported robot configuration.

The program can be used to test the calibration data that defines the camera-to-robot relationship, save the calibration data in disk files, and load calibration data from disk. In addition, the program provides simple methods for adjusting various image parameters that can affect the calibration.

If you have the Adept High-Accuracy Positioning System (HPS) option, the data from that system can be used during the calibration procedure to improve the accuracy of the camera-to-robot relationship. (See Appendix F for details on using HPS data with this program. Consult the manual for the HPS option for details on that system.)

Using the Calibration Program 5

ADV_CAL.V2 72
ADV_USER.V2 75
LOADAREA.V2 76

ADV_CAL.V2

Description

Camera calibration utility

Disk File Name

ADV_CAL.V2

Program Name

a.adv_cal

Function

Performs camera calibration

Details

The disk file ADV_CAL.V2 is a "protected" file. Programs in that file cannot be displayed, edited, or stored from memory to a disk. Also, the file cannot be copied from one disk to another with the FCOPY command. The disk-copy utility program (on the Adept Utility Disk in the file DISKCOPY.V2) can be used to make a backup copy of the entire distribution disk. That program can also be used to copy the file ADV_CAL.V2 from the distribution disk to the optional hard disk.

The steps below describe the overall procedure for executing the Advanced Camera Calibration program (ADV_CAL.V2). Details on each of the calibration program menu options are presented in **Chapter 6**.

Procedure

1. Clear the system memory with the ZERO command. (Make sure you save any programs or data.)
2. If data from the optional High-Accuracy Positioning System (HPS) is to be used:
   a. Load the HPS runtime routines.
   b. Use the program "hps.load" to load into memory the data for at least one HPS mapping for the robot being used. Mappings must be numbered consecutively starting with 1. (See **Appendix F** for more details on using HPS.)

NOTE: The following steps assume that your Advanced Camera Calibration program (ADV_CAL.V2) is stored on a floppy disk. If it is not, simply substitute the correct drive letter and directory name for "A:" below.

3. Insert the Advanced Camera Calibration disk into disk drive "A" in your Adept controller.[1]
4. Load the calibration program into system memory with the following command ("↵" indicates the Enter key must be pressed):

   ```
   LOAD A:ADV_CAL ↵
   ```

5. If you are want to create the robot-to-camera transformation during calibration, start-up calibration must be performed for the robot:

   ```
   ENABLE POWER ↵

   CALIBRATE ↵
   ```

   If you are not interested in the robot-to-camera transformation, or there is not a robot attached to your system, enable the dry run switch:

   ```
   ENABLE DRY.RUN ↵
   ```

6. Start execution of the calibration program with the command:

   ```
   EXECUTE a.adv_cal ↵
   ```

7. If a calibrated robot is not connected to the system or DRY.RUN is not enabled, the program will abort immediately. If ARM POWER is not enabled or DRY.RUN is enabled, the system will warn you that camera-to-robot calibration cannot be performed and ask you if you want to proceed.
8. You will now be asked to select a virtual and physical camera. All calibration options will be performed on this virtual/physical camera pair. One of the program menu selections lets you change the selected physical or virtual camera.
9. When a physical and a virtual camera have been selected, a menu of program options will be displayed. Select the desired option and follow the prompts displayed on the monitor. Make sure to use the "LOAD/STORE calibration data from/to disk" option to store the calibration data that you want to use later.
10. After exiting the calibration program, you can delete it from system memory with the commands:

    ```
    KILL ↵
    DELETE a.adv_cal ↵
    ```

---

[1] The disk drives in your system controller are described in your Adept controller user guide.

> **NOTE:** The above command will delete the camera-to-robot calibration data from memory unless the variables are referenced by some other program in memory that is not being deleted.

To restore the calibration data from the disk, you can do one of the following:

- Use the "LOAD/STORE calibration data from/to disk" menu option in the ADV_CAL.V2 program (see "LOAD/STORE Calibration Data From/To Disk Menu Options" on page 103)
- Create an application program that calls the subroutine **load.area( )** This subroutine is contained in the file LOADAREA.V2 on Adept Utility Disk #1. See "LOADAREA.V2" on page 76 for details.

ADV_USER.V2

Description

Routines for use with ADV_CAL and for using calibration data

Disk File Name

ADV_USER.V2

Details

The file ADV_USER.V2 is a public file located on the Adept Utility Programs disk.

ADV_USER.V2 contains utility programs that can be used by application programs that access the AdeptVision VXL system. The following subroutines are contained in the ADV_USER.V2 file.

ac.refine.vloc( ) is a subroutine that, if present while the calibration program is running, will automatically refine location of the vision objects using a VFIND.ARC instruction. This routine should be used only when the calibration object is supposed to be perfect circle. The name **ac.refine.vloc( )** must be retained, since it is the key for automatic use by the calibration program. See page 303 for a printout of this subroutine.

adv.cam.user( ) is a subroutine that can be called from an application program to take a picture with a camera and return the location (in robot coordinates) of an object located in the vision window. It will work for Adept-supported SCARA, XY, XYZ, and XYZ-Theta configurations (including the UltraOne). See page 305 for a printout of this subroutine.

adv.tr.point( ) is a subroutine that is called by **adv.cam.user( )**. It is used to transform a point using a 3x3 camera calibration matrix. See the program header for details. Also, see page 308 for a printout of this subroutine.

LOADAREA.V2

Description

Load area vision calibration data

Disk File Name

LOADAREA.V2

Program Name

load.area( )

Function

Restore area vision calibration by reading data from a disk file created by the Adept area vision calibration program.

Details

The file LOADAREA.V2 is a public file located on the Adept Utility Programs disk. This file contains the subroutine **load.area( )**. This subroutine can be called from an application program to read and restore the calibration data for the area vision system. It reads the calibration information from a disk file that was created by the Adept area vision calibration program, **a.area_cal( )**. The subroutine **load.area( )** enables the vision software, restores the taught state of the lighting threshold and backlight switch, and restores the camera location and scaling information.

Procedure

1. Place the Adept Utility Disk in disk drive A.[1]
2. To load the file LOADAREA.V2, enter the following command:[2]
   ```
   load a:loadarea
   ```
3. Use the system program editor to enter your application program into the system memory, or load your program from a disk file. Make sure the program calls the subroutine **load.area( )** (see below).
4. Place a diskette to receive your application program in disk drive A.

---

[1] Omit this step if the program file is already on your hard drive.

[2] Or use the correct drive and path specification if the file is stored on the hard drive.

5. Store your application program and the load.area subroutine in a disk file by typing:

   ```
   store a:file_name = name_of_your_main_program
   ```

   where *file_name* represents the name you want to assign to your disk file and *name_of_your_main_program* represents the name of the top-level program in your application program, which must logically refer to all the other routines for the application.

   Alternatively, type the command

   ```
   store a:file_name
   ```

   to store all the programs and data in the system memory into the specified file.

Programming Considerations

The **load.area( )** subroutine reads the area vision calibration information that is stored in a disk file. If the data are found to be valid, the following instructions are executed to initialize the vision system, and the data are returned to the calling program.

```
IF NOT SWITCH(VISION) THEN
     ENABLE VISION
END
PARAMETER V.THRESHOLD[camera_number] = stored_threshold_value
SWITCH V.BACKLIGHT[camera_number] = stored_backlight_value
VPUTCAL (camera_number) stored_calib_array[],
stored_pmm.to.pix[,], stored_pix.to.pmm[,]
```

After the routine has successfully processed the calibration data file, the AdeptVision system is ready to process images. All of the calibration data are returned to the calling program for completeness, but only the variable to.cam normally is utilized by the application program.

Your application program should call the subroutine at some point before the vision system is to be activated for visual processing. The subroutine normally needs to be called only one time (for each camera) per operating session. The CALL instruction must have the following format:

```
CALL load.area($file,cam,thresh,backlight,to.cam, cam.cal[],
     pmm.to.pix[,], pix.to.pmm[,], pmm.to.mm[,], mm.to.pmm[,], $err)
```

where the program arguments have the interpretations that are shown in the following.

NOTE: Although the CALL instruction is shown on two lines above, it must be completed on a single line in your application program.

The variable names used here are for explanation purposes only. Your application program can use any variable names you want.

$file	Input parameter that passes the specification of the disk file containing the area camera calibration data. This parameter can be a string constant, variable, or expression.

The file specification follows

```
disk_unit: name.extension
```

The file specification can also include a directory path, as follows

```
disk_unit: directory_path\name.extension
```

However, the file name and extension must have the form AREA*nnn*.DAT (where *nnn* is the data set number) if the data file was created by the Adept area vision calibration program **a.adv_cal**, or by VisionWare.

$err	If no error occurs while **load.area** is executing, the parameter **$err** receives an empty string ("") and the output parameters described below receive the indicated values. If an error does occur, $err receives a string describing the error and the other output parameters are not defined. Thus, your calling program should check the variable **$err** before proceeding.
cam	Input parameter and output parameter that identifies the (virtual) camera receiving the calibration data.

As an input parameter, cam specifies which virtual camera is to receive the calibration data. If this parameter is undefined or has the value zero, the camera number stored in the data file will be used. If cam has a nonzero value, it will be compared with the virtual camera number in the data file, and **$err** will be assigned a warning message if the camera numbers differ.

This parameter will be used as an output parameter if it was undefined (or zero) on input. Then, cam will return the virtual camera number used, as a real value in the range 1 to 32. (The physical camera number is contained in the **cam.cal[ ]** data array [see below].)

thresh Output parameter that receives the real value used to set the V.THRESHOLD system parameter.

backlight Output parameter that receives the real value used to set the V.BACKLIGHT system switch. The value will be either TRUE (–1) or FALSE (0).

to.cam Output parameter that receives the transformation value representing the position and orientation of the vision camera in the robot frame of reference.

This transformation must be combined with the transformation returned by the vision system whenever the robot is to be moved to an object in the field of view. For example, for a camera fixed over the workspace the robot could be moved to the location defined by

```
to.cam:vis.loc
```

where vis.loc is the transformation returned by a VLOCATE instruction.

NOTE: This example applies only if the camera is fixed over the workspace. For any other camera mounting, refer to Chapter 13 for the details of how to use the **to.cam** transformation.

cam.cal[ ] Output parameter that receives the area camera calibration data that is used in the VPUTCAL instruction (see above). This parameter must be a real-array variable. (For details on the elements of this array, see the description of the VPUTCAL instruction in the *AdeptVision Reference Guide.*)

The following output parameters return transformation matrices for dealing with perspective distortion. Each of these parameters must be a two-dimensional real-valued array variable. (If the calibration data file being read does not contain perspective data, these arrays receive simple scale transformations.)

NOTE: Refer to the *AdeptVision Reference Guide* for more information on perspective distortion in general, and on these arrays in particular.

pmm.to.pix[,] Output parameter that receives the millimeter-to-pixel transformation matrix.

pix.to.pmm[,] Output parameter that receives the pixel-to-millimeter transformation matrix.

pmm.to.mm[,] Output parameter that receives the transformation from real object space (in millimeters) to simple object space (in millimeters).

For efficiency, most vision tools are positioned with coordinates in simple millimeter space, and some tools (such as blob analysis) return coordinates in this space. The **pmm.to.mm[,]** transformation may be used to precisely position vision tools (such as VWINDOW and the graphics instructions) that do not automatically correct for perspective distortion.

NOTE: Using this correction is appropriate only when the perspective distortion is significant. Using the array **mm.to.pmm[,]** (see below) to correct the results of vision tools, however, may be desirable for increased precision even when the perspective distortion is slight.

mm.to.pmm[,] Output parameter that receives the transformation from simple object space (in millimeters) to real object space (in millimeters).

This array can be used to correct for perspective distortion in the results from vision tools that do not automatically convert the coordinates with the transformation **pix.to.pmm[,]** (for example, this is the case with blob or prototype locations).

Special Considerations

The subroutine load.area enables the VISION system switch, restores the stored settings of the V.THRESHOLD system parameter and the V.BACKLIGHT system switch, and restores the vision calibration data via the VPUTCAL instruction.

The subroutine **load.area( )** assumes that the calibration data file has the specific format used by the Adept area vision calibration program. The calibration program writes a format version number in the data file—this version number must agree with the one expected by **load.area( )**, or the loading is not performed.

The ADV_CAL Menus 6

Introduction . . . 83
Calibration Status Display . . . 83
Main Menu . . . 84
  Main Menu Options . . . 84
    Exit to system monitor . . . 84
    LOAD/STORE calibration data from/to disk . . . 85
    ADJUST camera/image settings . . . 86
    CALIBRATE the current camera . . . 86
    TEST current calibration (camera-to-robot) . . . 86
    COPY calibration between virtual cameras . . . 87
    CHANGE virtual and/or physical cameras . . . 88
    SELECT different robot . . . 88
ADJUST Camera/Image Menu . . . 89
  ADJUST Camera/Image Menu Options . . . 89
    RETURN to the main menu . . . 89
    ADJUST physical CAMERA ATTRIBUTES (live video) . . . 89
    ADJUST video GAIN and OFFSET (live video) . . . 90
    ADJUST binary THRESHOLD (live binary) . . . 90
    ADJUST vision WINDOW (processing boundaries) . . . 90
CALIBRATE the Current Camera Menu . . . 91
  CALIBRATE the Current Camera Menu Options . . . 95
    Camera only . . . 95
    Stationary camera with robot—General method . . . 95
    Calibration object attached to robot (general case) . . . 96
    Downward-looking stationary camera (using vacuum gripper) . . . 97
    Object on moving belt (robot downstream of camera) . . . 97
    Robot mounted camera—Robot can touch calibration object . . . 98
    Robot mounted camera—Known dot location . . . 99
    Robot mounted camera—Non-contact method . . . 99
    Link-2 mounted camera—Robot can touch calibration object . . . 100
    Link-2 mounted camera—Known dot location . . . 101
    Link-2 mounted camera—Non-contact method (single config.) . . . 101
    Link-2 mounted camera—Non-contact method (lefty/righty) . . . 102
LOAD/STORE Calibration Data Menu . . . 102

LOAD/STORE Calibration Data From/To Disk Menu Options 103
  LOAD calibration data from disk 103
  STORE calibration data to disk 103

Introduction

Operation of the Advanced Camera Calibration program (ADV_CAL) is directed by menu selections. There is a main menu with several selections. Some of these selections lead to multiple program functions and, therefore, invoke secondary menus, while other top-level menu selections invoke just a single program function.

This chapter describes each of the selections in the ADV_CAL menus. Three of the menu selections ("ADJUST camera/image settings", "CALIBRATE the current camera" and "LOAD/STORE data from/to disk") have their own menus. These menus are explained in detail in the following sections.

When the program is first started, you are asked to specify an initial virtual and physical camera. You can switch to different cameras later by using one of the selections in the main menu.

Calibration Status Display

A calibration status display is shown on the monitor screen above the main menu (and also during some of the selection processes). The virtual camera surrounded by pairs of asterisks is the virtual camera being calibrated. The status display shows the following information abut each virtual camera:

- The associated physical camera number
- The type and status of the calibration
- Whether this is a perspective calibration
- The image size (full frame or single field)
- The camera type (normal or shuttered)
- Whether HPS data was used during the calibration

If there is a valid calibration, its type is either camera-only ("CamOnly") or camera-to-robot. For camera-to-robot calibrations, the description is more specific, indicating how the camera was mounted with respect to the robot (for example, "Link-2" or "Fixed").

If the status is shown as "NoTrans", there is a valid camera-to-robot calibration array, but no calibration transformation is defined. If the status is "Invalid", there is a calibration transformation defined, but it was not created at the same time as the calibration array.

The program performs all its operations only on the "current" virtual camera and the currently selected robot. The current camera, which is highlighted in the status display, is selected when the program is first executed and can be changed with a menu selection. The currently selected robot is displayed at the lower left of the screen and can also be changed with a menu selection (only for systems with multiple robots).

Although the AdeptVision system has 32 virtual cameras, the status information is shown for only the eight cameras surrounding the current virtual camera. To view another group of eight cameras, simply change the current virtual camera to be within the desired group.

Main Menu

After a physical and virtual camera have been selected, the following menu is presented:

```
0 => EXIT to the system monitor

1 => LOAD/STORE calibration data from/to disk

2 => ADJUST camera/image settings

3 => CALIBRATE the current camera

4 => TEST current calibration (camera-to-robot)

5 => COPY calibration between virtual cameras

6 => CHANGE virtual and/or physical cameras

7 => SELECT different robot
```

Main Menu Options

Exit to system monitor

Choose this menu item when you want to exit the program and return to the V^+ system monitor.

Since several system parameters may have been changed (by you or by the program) during the calibration process, you are given the option of restoring the switches and parameters for all virtual cameras to the state they were in before the program was executed. If you do not choose this option, only a few switches and parameters associated with image processing (such as V.BINARY and V.BOUNDARIES) are restored. Other switches and parameters that are particular to your current application (such as the binary threshold and vision window boundaries) will be left as you set them while using the program.

If you want to exit the program at any prompt, press Ctrl+Z (hold down the Ctrl key and press "Z").

> **NOTE:** If you exit the program in this way (or abort using the ABORT command), there is no guarantee as to the status of the calibration or of any of the system switches or parameters. In addition, graphics windows used by the program may be left open and obscure the Monitor window.

LOAD/STORE calibration data from/to disk

This selection displays a secondary menu from which you can choose to load calibration data from disk, or store the current calibration to disk. Both selections will ask you for the disk unit to access and the "data set number" for the disk file to be accessed.

> **NOTE:** Calibration data may also be reloaded without using the calibration program. This is done by adding to your application program code that calls a subroutine to load the calibration data from disk. See "LOADAREA.V2" on page 76 for a description of this procedure.

The name of the camera calibration disk file has the format AREA*nnn*.DAT, where *nnn* is a user-specified data set number used to identify the calibration data in the file. As an aid to choosing a data set number, any calibration files currently on the selected disk are listed (with the description, if any, that was stored in each data file). You can cancel the load or store procedure by pressing just the Enter key in response to the prompt for the data set number.

When calibration data is loaded, the data is applied to the "current" virtual camera. If a different virtual camera is specified in the data file, a warning message is displayed on the monitor and the user is asked if the data should continue to be loaded.

> **NOTE:** Under certain circumstances, it may be possible to load calibration data created with an older AdeptVision (single-camera) system into an AdeptVision (multiple-camera) system, or vice versa. However, the resulting calibrations would be meaningless and *we highly discourage this practice*. New calibration data should be generated when changing from one type of AdeptVision system to another type of system.

See "LOAD/STORE Calibration Data Menu" on page 102 for details on loading and storing calibration data.

You will be returned to the main menu after the load or store process is completed.

ADJUST camera/image settings

This selection brings up a secondary menu with the options of adjusting physical camera settings, setting the binary threshold, setting the vision window boundaries, and setting the video gain and offset. See page 89 for full descriptions of these options.

CALIBRATE the current camera

This selection displays a secondary menu that lists the different calibration methods. More than one calibration method can be used for some camera mounting configurations. Thus, there are multiple menu selections for those camera mountings. See page 95 for a full description of each menu option.

For all camera-to-robot calibrations, if you have the High-Accuracy Positioning System (HPS) option, you can use HPS data for greater accuracy. See Appendix F for details on using HPS data.

TEST current calibration (camera-to-robot)

This selection is used to test the current camera-to-robot calibration. Testing is allowed only if there is a valid calibration for the current virtual camera.

As with the procedure for establishing the camera-to-robot relationship, HPS data can be used when testing the calibration. Thus, the program asks you if you want to have HPS data used. If you choose to use HPS data, the program makes sure all the required conditions are satisfied before continuing with the test. See Appendix F for details on using HPS data.

When testing the calibration, the program prompts you to position a calibration disk within the vision window. The general test procedure is for the program to take a picture, compute the location of the disk, and use the robot to determine the accuracy of that computed location. The specific procedure used for the test depends on which method was used to calibrate the current camera. The following paragraphs provide additional information about the test procedures used for some of the calibration methods.

- If a *pointer is being used*, the program assumes an Adept calibration disk (which has a tapered center hole) is also being used. The tip of the calibration pointer is moved over the computed location, set back about 15 millimeters along the Z axis of the robot tool. Then the program tells you to lower the pointer into the center hole. (If you do not wish to lower the pointer, simply click on DONE and the robot will return to the nominal position.) When you lower the pointer to the disk, it is very important that you move the pointer only along the TOOL Z axis. You should let the disk center itself on the end of the pointer. (You can assure that the pointer moves only along the TOOL Z axis by using "TOOL" mode on the manual control pendant, with the "Z" direction active.)

If the camera Z and tool Z axes are parallel, and the tool can rotate about its Z axis (often the case), you will be asked to place the pointer in the center hole four times, each time with the tool flange rotated 90 degrees from the previous position. Each time, let the disk center itself on the pointer. This procedure compensates for any offset that exists between the center of the robot quill and the tip of the pointer.

- If a *vacuum gripper is being used*, the calibration program assumes the calibration object can be picked up and put down reliably without changing its position.

  If the camera Z and tool Z axes are parallel, and the tool can rotate about its Z axis (often the case), the object will be viewed in 4 different orientations, each time rotated 90 degrees from the previous. This is done to compensate for any offset that exists between the center of the robot quill and the center of the gripper.

- If the *robot is holding the disk* in front of the camera, the robot is moved to the computed location (not set back from it). If you are using a two-sided card for a side-mounted camera, the program will rotate the robot quill 180 degrees and take another picture. If the camera Z and tool Z axes are parallel, and the tool can rotate about its Z axis (often the case), the object will be viewed in 36 different orientations, each time rotated 10 degrees from the previous.

  These actions are done to compensate for any offset that exists between the center of the quill and the center of the disk.

When the test is completed, the results are displayed as the difference between the computed position (based on the calibration data) and the actual position (as measured by the robot). The deviation is expressed in millimeters, inches, and camera pixels.

COPY calibration between virtual cameras

This selection is used to copy the following information from one virtual camera to another:

- The calibration array
- The camera-to-robot transformation (that is, an element in the array "to.cam[ ]", which is described later in this chapter)
- Status information regarding the camera-to-robot transformation

- The nominal robot location (that is, elements in the arrays "ac.nominal[ ]" and "ac.config[ ]", which are described later in this chapter)
- The offset from the calibration point to the center of the robot quill (that is, an element in the array "ac.offset[ ]", which is described later in this chapter)
- The settings of several system switches (for example, V.BACKLIGHT and V.HOLES)
- The values of several system parameters (for example, V.FIRST.COL and V.LAST.COL)

CHANGE virtual and/or physical cameras

This selection is used to change the current virtual camera number and/or the physical camera with which the virtual camera is associated. This is an important menu item because all the other menu items pertain only to the "current" virtual camera, which is marked by asterisks in the status block above the list of menu items.

When this menu item is selected, you are asked to enter (1) the number of the virtual camera you want to work with and (2) the number of the physical camera to use. For each prompt, you can simply press the Enter key to retain the corresponding current camera selection.

As mentioned above, the calibration status display shows a group of eight cameras that includes the current camera. The status information for another group of eight virtual cameras can be viewed by using this menu selection to change the current virtual camera to be within the desired group. (When you select a new virtual camera number, the default physical camera is the one previously associated with that virtual camera. Therefore, pressing the Enter key in response to the prompt for the physical camera will just change the virtual camera selected.)

SELECT different robot

> **NOTE:** This selection is available only for systems with multiple robots and is not displayed with nonrobot systems.

This selection is used to change the currently selected robot. This is an important menu item because all the other menu items pertain only to the "current" robot, which is indicated in the lower left of the display. When this menu item is selected, you are asked to enter the new robot number. The default robot number will be the current one.

ADJUST Camera/Image Menu

This section describes the secondary menu for adjusting the camera image. The following menu is displayed after selecting "ADJUST camera/image settings" from the main menu.

```
0 => RETURN to the main menu

1 => ADJUST physical CAMERA ATTRIBUTES (live video)

2 => ADJUST video GAIN and OFFSET (live video)

3 => ADJUST binary THRESHOLD (live binary)

4 => ADJUST vision WINDOW (processing boundaries)
```

Some system parameters may be changed by the following selections. However, you will have the option to restore all the camera switches and parameters to their original state when you exit the calibration program. If you choose *not* to have them all restored, only a few switches and parameters associated with image processing (such as V.BINARY and V.BOUNDARIES) will be restored. Other switches and parameters, which are particular to your current application (such as the binary threshold and window boundaries), will be left as you have set them while using the calibration program.

ADJUST Camera/Image Menu Options

RETURN to the main menu

Use this selection when you are finished making adjustments, and want to return to the main program menu.

ADJUST physical CAMERA ATTRIBUTES (live video)

This selection is used to select the camera model number, select the shutter and acquire modes, and adjust the physical camera settings. A live grayscale image is displayed to help you see the effects of adjusting the camera focus and aperture.

The camera model number is selected from a list of supported camera models. There are also "open" models available for storing custom camera configurations. See "Cameras Supported by AdeptVision VXL" on page 45 for details on supported camera models.

> **NOTE:** If you have an EVI board installed and the EVI license enabled, an additional choice (Pulnix TM-1001) appears on the camera model selection list.

The shutter and acquire modes are selected from a list of supported shutter and acquire modes. See "Cameras Supported by AdeptVision VXL" on page 45 for details on shutter modes.

The camera aperture setting controls the brightness and contrast; a smaller aperture (larger number) lets in less light, a larger aperture (smaller number) lets in more light. You should adjust the light level and camera aperture to eliminate any over-saturation in the white areas but still have a full range of gray values—from very light to very dark. This should provide a good, contrasting image.

During these adjustments, note that the aperture setting also affects the "depth of field". Depth of field refers to the range of distances in the camera field of view that are in (adequate) focus. The smaller the aperture, the greater the depth of field. Sometimes a well-focused image with optimum contrast is not possible. Then a trade-off must be made between allowing in more light for good contrast (larger aperture) and obtaining a greater depth of field (smaller aperture).

ADJUST video GAIN and OFFSET (live video)

This selection is used to adjust the video gain and offset. The live grayscale video image is displayed during this procedure. The effect of changing the gain and offset is immediately applied to the current image.

To adjust the video gain or offset, use the appropriate slide bar on the left of the monitor screen. When satisfied with both settings, click on **OK** . The values you have selected will be assigned to the system parameters V.GAIN and V.OFFSET for the current virtual camera. Click on **QUIT** to reset the gain and offset back to the settings they had when you chose this option.

ADJUST binary THRESHOLD (live binary)

A live binary image is displayed so you can examine and adjust the binary threshold. (The binary threshold is the grayscale level used to divide the entire intensity scale into just "white" and "black". During binary processing, all pixels with intensities above the binary threshold are considered "white", and all pixels with intensities below the threshold are considered "black".)

To adjust either of the binary thresholds, use the appropriate slide bar on the left of the monitor screen. When satisfied with both settings, click on **OK** . The values you have selected will be assigned to the system parameters V.THRESHOLD and V.2ND.THRESHOLD for the current virtual camera. Click on **QUIT** to reset the thresholds back to the settings they had when you chose this option.

ADJUST vision WINDOW (processing boundaries)

This selection allows you to use the mouse to change the boundaries of the window processed when VPICTURE operations are performed.

To adjust the window, simply click on and drag the upper left corner or the lower right corner. When satisfied with the boundaries, click on **OK** . The boundaries you have selected will be assigned to the system parameters V.FIRST.COL, V.LAST.COL, V.FIRST.LINE, and V.LAST.LINE for the current virtual camera. Click on **QUIT** to reset the window back to the setting it had when you chose this option.

CALIBRATE the Current Camera Menu

The Advanced Calibration program offers the following calibration options (accessed by selecting "3 => CALIBRATE the current camera"):[1]

```
0. Return to the main menu
1. Camera only (other methods use the robot)
   Stationary camera with robot...
     2. General method (not automated)
     3. Calibration object attached to robot (general case)
     4. Downward-looking camera (using vacuum gripper)
     5. Object on moving belt (robot downstream of camera)
   Camera mounted on robot (general case)...
     6. Robot can touch calibration object
     7. With known dot location
     8. Non-contact method (camera must rotate about Z)
   Camera mounted on link 2 of Adept SCARA robot...
     9. Robot can touch calibration object
     10. With known dot location
     11. Non-contact method (single configuration)
     12. Non-contact method (lefty/righty)
```

---

[1] This menu is displayed only for robot systems. For nonrobot systems, "camera only" is automatically selected.

> **NOTE:** For the "noncontact" camera-to-robot calibration methods (8, 11, 12), we assume that the camera is pointed along a line that is perpendicular to the surface of the calibration object. Except as noted below, inaccuracies could result if this is not the case.

At the beginning of each calibration procedure:

1. If DRY.RUN is enabled or you are calibrating a nonrobot system, you will be advised that camera-only calibration will be performed.
2. You will be asked to verify that you have a calibration object.
3. You will be asked to check the image parameters. If you select this option, you will be presented the same options as if you had selected the "Adjust Camera/Image Settings" menu option. See page 89 for details.

   While checking the image parameters, you also will be able to set the camera type and image acquire mode. There are four options:

   - No Shutter, Full-Frame acquire
   - No Shutter, One-Field acquire
   - Synchronous Shutter, One-Field acquire
   - Asynchronous Shutter, One-Field acquire

   Select "One Field" to use half-resolution images (only 242 lines high). If the camera has been set to operate in shuttered mode, select one of the shuttered options (shuttered operation requires one-field acquires). See the description of VPUTCAL in the *AdeptVision Reference Guide* for details on these features.

For all but the "noncontact" camera-to-robot calibration methods, calibration will be performed with perspective compensation. The resulting calibration will be accurate even if the work surface is not perpendicular to the camera's line of sight. However, since use of this kind of calibration slows down some vision tools, you will be given the option of using an approximation (called "basic calibration") instead. A basic calibration simply uses millimeter-per-pixel and X/Y-ratio numbers for the center of the screen as the calibration numbers for the whole image. In many cases, this may yield sufficient accuracy. To help in deciding when a basic calibration will be acceptable, the maximum error (in position displacement) to be expected when using a basic calibration (as opposed to the perspective calibration) is displayed.

In addition, after a perspective calibration is computed, a large white arrow (resembling two lines converging at the horizon) indicates the approximate direction in which the calibration surface is tilted away from the camera.[1] Eliminating this tilt will result in a much better basic calibration. Even if using a perspective calibration, it is best to use a nontilted calibration surface (if possible), since not all vision tools do perspective compensation.[2]

If you are not interested in location information from the vision system (for example, you are going to use the vision information only for inspections), you may skip to the description of the "Camera only" calibration selection. Otherwise, you should read the following general material so you will be better able to understand the procedure for camera-to-robot calibration.

For any calibration involving the robot, the program will prompt you to define a "nominal" robot location. For fixed-mount cameras, the nominal location should allow a clear and shadow-free vision window. If the robot is to hold the disk in front of the camera during calibration, the nominal robot location should position the disk near the center of the vision window. For calibration of a robot-mounted camera, the nominal location should be as close as possible to the picture-taking location that will be used during the application runtime.

> **NOTE:** When performing camera-to-robot calibrations in MANUAL mode on an EN954 Safety Category system, a prompt appears on the MCP:

```
Hold down Speed Pot and STEP buttons.
```

After completion of the calibration procedure, the nominal location is recorded in the global location variable "ac.nominal[v]", where "v" is the current virtual camera number. Similarly, the robot configuration (RIGHTY or LEFTY) at the nominal location is recorded in the global variable "ac.config[v]". See **"Miscellaneous Global Variables" on page 109** for more details on these and other global variables defined during calibration.

If the pointer or vacuum gripper used to touch the disk during calibration is not to be centered on the tool's axis of rotation, a TOOL transformation should be defined to describe the tool offset. Computed robot locations that are based on vision information assume that either the TOOL transformation was correct during calibration, or that the tool offset is the same as it was during calibration. However, the program will be compensate for small tool offsets or small errors in the TOOL if the tool can rotate about its Z axis (and the Z is perpendicular to the work surface).

---

[1] The arrow's direction will not be accurate for errors of less than 2 pixels.

[2] VFIND.LINE, VFINDARC, VFINDPOINT, VRULER, and VRULERI use perspective calibration and will be affected by selecting basic vs. perspective calibration.

> **NOTE:** For vertically mounted cameras, a "grip" transformation can often be defined that will compensate for an incorrect TOOL transformation during calibration, or compensate for the use of a different end-effector. Grip transformations are described in Chapter 13.
>
> For off-vertical (odd-angled) camera mountings, the TOOL transformation must be correct during calibration. Otherwise, the calibration will be inconsistent and probably inaccurate.

For most calibration configurations, you will be asked if the tool's Z axis is perpendicular to the work surface and if the tool can rotate about its Z axis. If these are true, then the tool is said to have "theta capability" with respect to the vision coordinate frame. When the tool has theta capability, the program will automatically compute any offset of the pointer from the tool Z axis or errors in the TOOL transform that occur in the X-Y plane of the vision coordinate frame. This offset will be used during the calibration process and left in the global transformation variable "ac.offset[v]", where "v" is the current virtual camera number. If the tool does not have theta capability, then this transformation variable will be assigned the value NULL (for cameras that have been calibrated). See "Miscellaneous Global Variables" on page 109 for details on this and other global variables defined during calibration.

When a calibration pointer is used and the tool has theta capability, the program will take four pictures of the calibration disk, each with the tool rotated 90 degrees from the previous one. Before each picture, it will ask you to lower the pointer along the tool Z axis to the center of the disk. Each time (except for the first) that you lower the pointer into the center hole, *do not* move the pointer in the direction of the tool X or Y axis—just lower the pointer along the tool Z axis. You may move the disk, if necessary, to allow the disk to center itself on the pointer. You will have to do this only once for a calibration. Information from the four pictures will allow the program to compute the pointer or TOOL offsets from the tool Z axis.

Vacuum grippers can be used only if the tool has theta capability. In this case, the program will automatically pick up and put down the calibration object four times, each time rotating it 90 degrees with respect to the last orientation. Information from the four pictures will allow the program to compute the pointer or TOOL offsets from the tool Z axis.

For camera-to-robot calibration, you can have the program use HPS data to improve the accuracy of the calibration results. If you select the option to use HPS data, the program ensures that all the required conditions are satisfied before continuing with the calibration. See Appendix F for more information on using HPS data.

After successful camera-to-robot calibration, you will have a chance to test the calibration and to save the calibration data in a disk file.

CALIBRATE the Current Camera Menu Options

Camera only

When you are not interested in location information from the vision system, you can use "camera only" calibration to establish the relationship between the camera image and the physical scene. This method does not calculate a camera-to-robot transformation.

The camera-only calibration procedure is designed for use with the precision calibration sheet provided by Adept (in the *AdeptVision Reference Guide*). The calibration sheet has one large and five small targets (sets of nested squares). Use the set of nested squares ("target") that best fits in the vision window.

If the Adept calibration sheet is not available, you can use one of the calibration disks provided by Adept, or any object that contrasts with its background (the material used should not be stretchable). If you do not use the Adept calibration sheet, you will be asked to enter the size of the object (in millimeters). The accuracy of the resulting calibration data will depend on the accuracy of the value entered for the diameter or width. Measure your disk carefully. See Appendix G for details an creating your own calibration target.

For this calibration method, the camera can be located anywhere in the workcell—at a fixed location or mounted on the robot. The important point to remember is that the camera-only calibration is accurate only for cameras that are in the same location as when they were calibrated. Thus, if a camera calibrated as "Camera only" is mounted on a robot, your application program will need to move the robot to the calibration location before taking each picture.

When the camera cannot be pointed squarely at the vision target, you must use perspective calibration.

Stationary camera with robot—General method

This general calibration method can accommodate a camera at any angle, as long as the camera is always at the same location with respect to the robot base when the robot is at its nominal location. Also, there must be a pointer or vacuum gripper attached to the end-effector of the robot. If a pointer is used, you must be able to place it precisely at the center of the calibration disk for each calibration data point. For best results when using a pointer, you should use an Adept calibration disk.

It is possible to use a vacuum gripper only when the tool's Z axis is perpendicular to the work surface and the tool can rotate about its Z axis. If you use a vacuum gripper, the calibration object may be a disk, dot, or any simple shape (see **"Calibration Object" on page 65**).

The calibration transformation computed by the program represents the relationship between the robot base coordinate frame and the vision coordinate frame for the plane on which the disk is moved around.

This calibration procedure involves manually moving the calibration disk to different positions in the vision window and then touching the pointer or gripper to the center of the disk. After four data points have been recorded (the minimum needed to compute a calibration), the program will automatically position the end of the tool over each successive disk position. This makes it easy to gather additional data points to refine the calibration. Using multiple points will significantly increase the precision of the calibration. Monitor the statistics printed each time the calibration is calculated to determine when you have a sufficiently consistent calibration.

If the tool's Z axis is perpendicular to the work surface and the tool can rotate about its Z axis, then a special procedure is used when recording the first data point so the program can compute any offset that exists from the tip of the pointer to the Z axis of the tool. You will be asked to place the pointer in the center hole four times, each with the tool rotated 90 degrees from the previous time. Each time the pointer is lowered into the center hole, let the disk move as required to center itself on the pointer. However, *do not* move the pointer in the X or Y directions—just lower it along the tool Z axis. If a vacuum gripper is used, rough placement of the gripper near the center of the disk is sufficient. Also, for a vacuum gripper, this rotation procedure will be automatic but will occur at each point.

If the camera is not mounted vertically, it may not be appropriate to use HPS data. See **Appendix F** for details on using HPS data.

Calibration object attached to robot (general case)

Specific common camera setups covered by this method are: upward-looking cameras, an X-Y table with overhead camera, and horizontally mounted cameras.

This method assumes that the camera is mounted in a fixed position with respect to the robot base. The calibration object must be attached to the robot tool tip (as defined by any TOOL transformation), and the orientation of the tool tip be must such that its Z axis is roughly parallel to the Z axis of the camera.

The center of the calibration object should be as close to the tool tip location as possible. However, if the tool tip can rotate about its Z axis (one of the questions asked during calibration), then the program will compensate for any offset from the tool tip. On the other hand, if the tool tip cannot rotate, then the center of the calibration object must be precisely at the tool tip location. This can be done using the TOOL transform.

To get a good thresholded image, we suggest that the calibration dot (or other simple shape) be drawn on a rigid surface that is large enough to always fill the field of view. Otherwise, the robot itself, or the overhead scene, can cause a complicated background that is difficult to screen out by adjusting the vision parameters.

Downward-looking stationary camera (using vacuum gripper)

This calibration method is for a camera that points vertically downward, with its position fixed with respect to the robot base. This procedure requires that a vacuum gripper be attached to the robot, that the gripper point along the Z axis of the tool, and that the gripper can be rotated about this axis.

After you place the calibration object in the field of view and place the vacuum gripper on the object (near its center), the robot will automatically move the object around in the image area. The robot will move to the nominal location when each picture is taken.

Since this method uses a vacuum gripper, the calibration object may be a disk, a dot, or other simple shape (as described earlier).

Object on moving belt (robot downstream of camera)

This method is for calibrating cameras that are looking at a conveyor belt upstream of the robot's work area. The conveyor belt must be calibrated with the Conveyor Belt Calibration and Testing Program (on the Adept Utility Disk), and the belt calibration must be stored on disk.

This calibration method can accommodate a camera at any angle, as long as it can adequately view the surface of the belt and is always at the same location with respect to the robot base (robot-mounted cameras must be at their calibration location). Also, there must be a pointer attached to the end-effector of the robot. This method uses one of the Adept calibration disks.

This calibration procedure involves manually moving the calibration disk to different positions in the field of view and then advancing the belt to put the disk within reach of the robot and placing the pointer in the center of the disk (*without moving the disk*).

The calibration transformation computed by the program represents the relationship between the robot base coordinate frame and the vision coordinate frame for the plane in which the disk is moved around. The frame is calculated using the current belt calibration, but once the frame is calculated, the frame is not related to any belt calibration. The results are the same as for any fixed camera calibration.

> **NOTE:** We recommend that you attach the disk to the belt for each calibration location. Double-stick tape works well. If the disk moves *at all* (relative to the belt) between the time the upstream and downstream pictures are taken and when you establish the disk's location with the robot, a less accurate calibration will result.

After four data points have been recorded (the minimum needed to compute a calibration), the program will compute a calibration and use it to automatically position the end of the tool over each successive disk position as you calibrate. This makes it easy to gather additional data points to refine the calibration. Monitor the statistics printed each time the calibration is calculated to determine when you have a sufficiently precise calibration.

If the camera is not mounted vertically, it may not be appropriate to use HPS data. See **Appendix F** for details on using HPS data.

Robot mounted camera—Robot can touch calibration object

This method is for the general case of the camera being mounted on the robot. The camera may be mounted on any link except link 1. The mounting must be such that the camera can be moved around in both X and Y directions parallel to the work surface. The calibration transformation determined is the relationship between the robot link the camera is mounted on and the vision coordinate frame.

> **CAUTION:** The camera should be mounted such that it cannot make contact with the robot outer link or equipment attached to the robot.

If you use a vacuum gripper, the calibration object may be a disk, a dot, or any other simple shape (as described in **"Calibration Object" on page 65**). To start the calibration process, place the vacuum gripper on the calibration object near its center. (The gripper must be centered carefully if the vision window is small.) The program will then automatically determine the precise location of the calibration object.

If you use a pointer, you should use an Adept calibration disk with a tapered center hole. If the tool has theta capability, you will be asked to place the pointer in the center of the disk four times, each time with the tool rotated 90 degrees from the previous position. This will allow the program to determine the precise location of the disk.

After one of the above procedures, you will be asked to position the camera four times such that the object appears in the vision window in four different quadrants. The calibration will then complete automatically.

Robot mounted camera—Known dot location

This method is for the general case of the camera being mounted on the robot. The camera may be mounted on any link except link 1. The mounting must be such that the camera can be moved around in both X and Y directions parallel to the work surface. The calibration transformation determined is the relationship between the robot link the camera is mounted on and the vision coordinate frame.

This method requires that you provide the location of the dot that will be used in the calibration. You can specify the dot location in any of the following ways:

1. Specify a virtual camera (other than the current one) with a good calibration for the same physical camera and mounting. The program then uses that virtual camera to obtain the dot location automatically.
2. Assign the location to the global variable "ac.dot.loc" prior to starting the calibration program.
3. Manually enter the X, Y, and Z values of the location when the program asks for them.

For greatest accuracy, the dot should be in the area for which the calibration will be used. Also, when using another virtual camera calibration to determine the dot location, that calibration should have been performed in the same area as the new calibration will be performed.

After the dot location has been determined, you will be asked to position the camera four times such that the object appears in the vision window in four different quadrants. The calibration will then complete automatically.

Robot mounted camera—Non-contact method

This method is for the general case of the camera being mounted on the robot. The camera may be mounted on any link except link 1 or 2. The mounting must be such that the camera can be moved around with X, Y, and RZ motions relative to the work surface. The calibration transformation determined is the relationship between the robot link the camera is mounted on and the vision coordinate frame.

NOTE: For this calibration method, perspective calibration *cannot* be used. The camera must be mounted perpendicular to the work surface.

CAUTION: The camera should be mounted such that it cannot make contact with the robot outer link or equipment attached to the robot.

WARNING: To accommodate mounting on the quill of Adept SCARA robots, the program uses the instruction SINGLE ALWAYS to ensure that the quill does not rotate excessively during calibration. Because of this, it is *required* that joint #4 be in the range ±180 degrees at the start of the calibration procedure (when the robot is at the nominal location). Otherwise, a rapid 360-degree rotation of the quill (and camera) could occur during the calibration procedure.

With this method, you will be asked to position the camera so that the dot appears in 5 unique locations in the vision window. It is *imperative* that these locations represent significantly different viewing orientations of the dot. The total variation in viewing orientation should be at least 120 degrees and preferably a full 360 degrees. After these first five images, the program will complete the calibration automatically, attempting to rotate the camera to obtain a full 360-degree variation in view angle among all the data points. If some robot positions are not valid, they will be skipped.

NOTE: The calibration data resulting from this method is usually not so accurate as data resulting from the method that involves touching the part (see above). Use this method only if it is not possible to use the contact method.

Link-2 mounted camera—Robot can touch calibration object

This method assumes that the camera is pointing vertically *downward* and is mounted on the second ("outer") link of an Adept SCARA robot. The calibration transformation determined is the relationship between robot link #2 and the vision coordinate frame.

If you use a vacuum gripper, the calibration object may be a disk, a dot, or any other simple shape (as described in "Calibration Object" on page 65). To start the calibration process, place the vacuum gripper on the calibration object near its center. (The gripper must be centered carefully if the vision window is small.) The program will complete the calibration automatically.

If you use a pointer, you should use an Adept calibration disk with a tapered center hole. You will be asked to place the pointer in the center four times, each time with the quill rotated 90 degrees from the previous position. After you lower the pointer the fourth time, the program will complete the calibration automatically.

Link-2 mounted camera—Known dot location

This method assumes that the camera is pointing vertically *downward* and is mounted on the second ("outer") link of an Adept SCARA robot. The calibration transformation determined is the relationship between robot link #2 and the vision coordinate frame.

This method requires that you provide the location of the dot that will be used in the calibration. You can specify the dot location in any of the following ways:

1. Specify a virtual camera (other than the current one) with a good calibration for the same physical camera and mounting. The program then uses that virtual camera to obtain the dot location automatically.
2. Assign the location to the global variable "ac.dot.loc" prior to starting the calibration program.
3. Manually enter the X, Y, and Z values of the location when the program asks for them.

For greatest accuracy, the dot should be in the area for which the calibration will be used. Also, when using another virtual camera calibration to determine the dot location, that calibration should have been performed in the same area as the new calibration will be performed.

With this method, simply position the camera such that the dot appears in the center of the vision window and let the program run.

Link-2 mounted camera—Non-contact method (single config.)

This method assumes that the camera is pointing vertically *downward* and mounted on the second ("outer") link of an Adept SCARA robot. The calibration transformation determined is the relationship between robot link #2 and the vision coordinate frame.

> **NOTE:** For this calibration method, perspective calibration *cannot* be used. The camera must be mounted perpendicular to the work surface.

With this method, simply place the calibration disk approximately in the center of the vision window and let the program run.

NOTE: The calibration data resulting from this method is usually not so accurate as that resulting from the other methods. Use this method only if no other calibration method is possible for a camera mounted on link #2, or if simplicity is more important than accuracy.

Link-2 mounted camera—Non-contact method (lefty/righty)

This method assumes that the camera is pointing vertically *downward* and is mounted on the second ("outer") link of an AdeptOne, AdeptThree, Adept PackOne, or Adept 604-S robot. The calibration transformation determined is the relationship between robot link #2 and the vision coordinate frame.

NOTE: For this calibration method, perspective calibration *cannot* be used. The camera must be mounted perpendicular to the work surface.

With this method, place the calibration disk approximately in the center of the vision window and follow the instructions given on the monitor and pendant.

This method can be used only with AdeptOne, AdeptThree, Adept PackOne, and Adept 604-S robots, since it takes advantage of both the LEFTY and RIGHTY arm configurations. About halfway through the automatic calibration procedure the arm will change configurations. At that time, you will be prompted to press the Enter key to proceed with the configuration change.

WARNING: Make sure the robot can change configuration without damaging the camera or any other devices in the workcell. Press the Enter key only when you are sure the robot can move safely.

NOTE: We recommend that HPS data be used with this method since the accuracy of a robot is difficult to maintain across configurations. If HPS data is used, a map must be made with each arm configuration. See Appendix F for details.

LOAD/STORE Calibration Data Menu

NOTE: Calibration data may also be reloaded without using the calibration program. This is done by adding code in your application program that calls a subroutine to load the calibration data from disk. See "LOADAREA.V2" on page 76 for a description of this procedure.

The Advanced Camera Calibration program provides the ability to store calibration data in a disk file and to retrieve the data from a disk file.

> **NOTE:** Stored calibration data is valid only if the following have not changed since the camera was calibrated: the camera mounting, the camera adjustments, and the distance from the camera to the work surface.

Select "LOAD/STORE calibration data from/to disk" and the following secondary menu is displayed:

```
0 =>  RETURN to the main menu

1 =>  LOAD calibration data from disk

2 =>  STORE calibration data to disk
```

LOAD/STORE Calibration Data From/To Disk Menu Options

LOAD calibration data from disk

To retrieve stored calibration data, select "LOAD calibration data from disk". The program asks which disk drive and directory to read calibration data from (drive and path specification is described in the previous section). After the disk and directory are specified, the program displays the names and comment lines for all the calibration files in that directory.

You can then enter the number of the file to load, or press the Enter key to cancel the load operation.

> **NOTE:** The current virtual camera number is compared with the camera number stored in the calibration data file. If they are different, you will be asked if you want to continue loading the selected data file for the current virtual camera. In this case, the virtual camera number in the data file will be ignored.
>
> Calibration data created with one type of AdeptVision system (for example, AdeptVision XGS) should *not* be used with another type of AdeptVision system (for example, AdeptVision AGS).

Once the calibration data is restored, the virtual camera is ready for use. Calibration data must be reloaded only when the system controller has been rebooted or system memory has been cleared.

STORE calibration data to disk

When you select "STORE calibration data to disk", you will be asked to specify the disk drive you want the data stored on. That is, drive "A", "B", "C", or "D".

You will also be asked to enter the directory path to be used. You can respond in any of the following ways:

- Simply press the Enter key to have the program access the top-level directory of the selected disk if the current default directory specification does not include a directory path, or if the selected disk unit is different from the disk specified in the current default.

  If the current default directory specification includes a directory path *and* if the selected disk unit is the same as the one in the default specification, the default directory path will be used.

- Enter a single backslash character ("\") to access the top-level directory on the selected disk, regardless of the current default specification.
- Enter a directory path to be used (a terminating backslash is not required). If the specified path does not begin with a backslash, *and* if the selected disk unit is the same as the one in the default specification, the path entered will be *appended* to the current default.[1]

After the disk and directory to be accessed are defined, the program will display the names of all the calibration data files that already exist in that directory, along with any description lines they contain.

Next you will be asked to enter a number from 0 to 999 to designate the disk file to which the calibration data will be written. The file created will be named "AREAnnn.DAT" where 'nnn' is the number you enter.

Finally, you will be asked to enter a short, one-line description of the camera setup being used. This information is stored in the disk file along with the calibration data.

---

[1] See the command DEFAULT DISK in the V+ *Language Reference Guide* for details.

Calibration Results

7

Introduction 106
Vision Calibration Array 106
Perspective Transformations 108
Camera-to-Robot Transformation 109
Miscellaneous Global Variables 109
    Location Array “ac.offset[ ]” 109
    Location Array “ac.nominal[ ]” and Real Array “ac.config[ ]” . 110

Introduction

This chapter describes the data generated during the calibration process. This data includes: a calibration array and perspective transformations and (for robot-related calibrations) a camera-to-robot transformation. This data can be saved on disk, and later read from disk. See "LOAD/STORE Calibration Data Menu" on page 102 and "LOADAREA.V2" on page 76 for details.

Vision Calibration Array

The fundamental result of camera calibration is that the appropriate information is specified to the vision system using the VPUTCAL program instruction. This information is in two parts: the vision calibration array and the perspective transformations. The perspective transformations are described in the next section. The vision calibration array is used by the vision system to determine which physical camera to use when taking a picture, the type of camera used (normal or shuttered), and the camera acquire mode (full frame or single field).

The other entries in the calibration array are not used directly by the vision system. One such entry is the code for the calibration method (array index 2). This code indicates which method was used to create the calibration (for example, camera-only, fixed-mount camera, or link-2 mounted camera). Also, the link number that the camera is mounted on (if applicable) can be found in array index 3. Entries such as these (specifically, array elements 2, 3, 9, 10, and 11) are guaranteed to be valid only if the calibration is loaded using an official Adept program. See "LOAD/STORE Calibration Data Menu" on page 102 and "LOADAREA.V2" on page 76 for details.

Table 7-1 lists the elements of the calibration array for area-camera AdeptVision systems. (This information also is listed in the *AdeptVision Reference Guide.*)

Table 7-1. Elements of Vision Calibration Array

Index	**Name**	**Value or Meaning**
0	calibrated	Calibration status: 0 => Uninitialized 1 => Initialized for calibration 2 => Okay (calibrated)
1	cam.num	Physical camera number

Table 7-1. Elements of Vision Calibration Array (Continued)

Index	Name	Value or Meaning
2	method	Calibration method and link mounting used: 1 => Camera-only 2 => Stationary, object in hand 3 => Downward mounted (with vacuum gripper) 5 => Robot mounted 6 => Robot mounted (known position) 7 => Robot mounted (no-touch) 16 => Link-2 mounted (touch part) 17 => Link-2 mounted (known dot location) 18 => Link-2 mounted (no-touch) 19 => Link-2 mounted (no-touch, lefty/righty) 64 => General stationary 65 => Fixed camera, object on belt
3	link.num	Link number of the robot that the camera is fixed with respect to.
4	y.scale	Vertical scale factor: (mm/pixel)/8 (an error will result if y.scale = 0)
5	y.transl	Must be 0
6	z.constant	Must be 0
7	v.pitch	Pitch angle: 0 or 180 degrees (see text)
8	neg.angle	–1 => Negate vision angles (see text) +1 => Don't negate angles (leave them alone)
9	to.cam.x	X component of calibration transform (see text)
10	to.cam.y	Y component of calibration transform (see text)
11	to.cam.rz	RZ component of calibration. transform (see text)
12	mm.per.pulse	Must be duplicate of "y.scale"
13	flags	A bit field containing several flags: Bit 1: 0 => HPS not used, 1 => HPS used Bit 2: 0 => Full frame acquire, 1 => Field Bit 3: 1 => Asynchronous shuttered camera Bit 4: 1 => Synchronous shuttered camera (Bits 3 and 4 are mutually exclusive)
14	xy.ratio	Camera pixel height/width (converts X to Y)
15	x.scale	Horizontal scale factor (mm/pixel)
16	y.scale	Vertical scale factor (mm/pixel)

Table 7-1. Elements of Vision Calibration Array (Continued)

Index	**Name**	**Value or Meaning**
17	cam model	0 = Normal RS-170 camera (Panasonic GP-MF702, Sony XC-77, etc.) 1 = Panasonic GP-CD40 2 = Reserved 3 = MF-702 asynch reset mode (noninterlaced full frame 30Hz) 4 = MF-702 asynch reset mode (interlaced full frame) 5 = MF-552 asynch reset mode (interlaced full frame) 6 = Pulnix TM-1001 7-10 = Reserved 11-15 = Initially, same as 0.
18	pixel compensation table	Index 1-8 of pixel compensation table used for filling in missing pixels; 0 = no pixel compensation

Previous Adept vision calibration programs set the values of the "v.pitch" and "neg.angle" array elements to 180 and –1, respectively, for most situations. This practice can be overly restrictive (and, in some cases, it is incorrect) for the general calibration methods supported by the Advanced Camera Calibration program. Therefore, this program always sets these elements to 0 and 1, respectively. This means a "grip" transformation, which describes the orientation with which to approach a computed location, must always be defined.

CAUTION: A new grip transformation should be defined whenever new calibration data is computed. Failure to use a valid grip transformation could cause the robot to run into the part or the work surface when moving to a location determined from a vision image.

Perspective Transformations

These are not transformations in the normal V^+ sense, but are 3x3 arrays that can be used to transform a point from pixels to millimeters or vice versa. For more information, refer to the description of LOADAREA in the *Instructions for Adept Utility Programs*. Also, refer to the program "ac.refine.vloc" on page 303 and the description of the VPUTCAL instruction in the *AdeptVision Reference Guide*.

Camera-to-Robot Transformation

During camera-to-robot calibration, the relationship of the camera coordinate frame to that of the robot is established. The relationship is recorded in the global location variable "to.cam[v]", where 'v' is the current virtual camera number. (The calibration transformation is meaningless for camera-only calibration. Therefore, a transformation is not defined by that method.)

The elements "to.cam.x", "to.cam.y", and "to.cam.rz" in the calibration array provide only a partial representation for the calibration transformation (see below). Adept recommends that you *not* use these array elements (which are supplied only for compatibility with previous programs). Instead, you should use the calibration transformation defined by the camera calibration program.

See Chapter 13 for details on using the calibration transformation in an application program.

Miscellaneous Global Variables

There are three global arrays of variables defined during the calibration procedure that may be used by application programs. These variables are not saved on disk when the calibration program stores calibration data to disk.

Location Array "ac.offset[ ]"

For calibrations where the tool's Z axis is parallel to the camera Z axis and the tool can rotate about its Z axis, the program automatically determines any offset of the tool tip (including TOOL) from the tool's real axis of rotation. This offset is only in the X-Y plane of the tool. It is used during the calibration process and is left in the global transformation variable "ac.offset[v]", where 'v' is the virtual camera number.

The offset transformation is defined relative to the robot tool tip (including any TOOL transformation used during calibration). That is, the rotation mentioned above is performed about the tool axis. Therefore, if you have a TOOL transformation defined, the offset will be relative to the resulting, ultimate tool tip. If the TOOL transformation was originally meant to make the center of rotation be at the center of an offset pointer, then "ac.offset[v]" could be used to correct that TOOL transformation. The transform goes from the tool tip back to the actual axis of rotation. Therefore, tacking INVERSE(ac.offset[v]) on to the existing tool tip (on top of any existing TOOL), would correct for any offset from the actual center of rotation.

This transformation value could also be used to determine the exact location of a fixed dot, etched on a gripper, that is used for calibration of a fixed camera.

Location Array "ac.nominal[ ]" and Real Array "ac.config[ ]"

All the calibration methods that involve the robot make use of a "nominal" location. This is the robot location that puts the calibration dot or disk in the vision window, with no obstructing objects in sight.

The nominal location for each virtual camera is defined completely by the global variables "ac.nominal[v]" and "ac.config[v]", where 'v' is the virtual camera number. The robot location is stored in the transformation variable "ac.nominal[v]" and the robot configuration (1 for RIGHTY and 0 for LEFTY) is stored in the real-valued variable "ac.config[v]".

You have a chance to define or redefine these variables during the calibration procedure and again when testing the calibration. The most recent definition is the one that will be found in the global variables after you exit the calibration program.

Programs for applications using fixed-mount cameras can use these variables to define a location where the robot will be clear of the camera field of view. By moving the robot to the nominal location (with the correct configuration), you will be assured that the robot is out of the camera field of view.

For calibration of a robot-mounted camera, maximum accuracy will be obtained if all pictures are taken from the nominal location.

If you do not plan ever to change the robot configuration during the application, then you do not need to consider the variable "ac.config[ ]". However, if both robot configurations are used in your application, you will need to change to the appropriate configuration before moving to the location "ac.nominal[ ]".

Teaching AdeptVision to See

8

Introduction 112
    Physical vs. Virtual Cameras 112
    The Point of Origin 113
VPICTURE—Getting an Image 114
    VPICTURE Syntax 114
        VPICTURE Examples 115
    Executing VPICTURE From the Menu 115
VDISPLAY—Displaying the Image 115
    VDISPLAY Syntax 116
        VDISPLAY Examples 116
    Executing VDISPLAY From the Menu 117
    Using the Different Display Modes 117
        Live Modes 117
        Frame (Frozen) Modes 118
        Graphics Mode 118
Binary vs. Grayscale Operations 118
Switches and Parameters 122
Using Switches 123
    Enabling/Disabling Switches 123
    Viewing Switch Settings 123
        SWITCH Example 124
    Image-Acquisition Switches 124
Using Parameters 125
    Setting Parameters 125
        Parameter Examples 125
    Image-Acquisition Parameters 125
Examples of Switch and Parameter Settings 127

Introduction

Your vision system should be installed and turned on (Chapter 2), and the camera should be calibrated and ready to start taking pictures (Chapter 3–Chapter 5).

This chapter describes ways of getting the camera to "see" the critical features of an object. The AdeptVision VXL system provides several options for "filtering" the information supplied by the camera so that the system analyzes only the features of an object that are important to you. Other options help you produce the clearest, most usable image possible.

Chapters 9–11 show you how to gather information from the images that this chapter shows you how to acquire. A thorough understanding of this chapter will help you make efficient, consistent use of the information the system returns to you and the tools the system makes available to you.

When the AdeptVision VXL system is started, the vision window is displayed in the upper-right corner of the screen. Most of the options described in this chapter can be performed from the vision window pull-down menus. This menu system provides you with an excellent development environment that allows you to experiment with the system options before you begin programming vision applications. Use this environment to become as familiar as possible with the effects of all the commands and options before you begin programming. You will write more efficient and accurate programs when you fully understand the vision processes.

> **NOTE:** The ObjectFinder tool cannot be accessed through the vision window's pull-down menus. However, there is a fully supported menu-driven interface available for the ObjectFinder in the AIM VisionWare module.

Several of the instructions presented in the following chapters are in abbreviated form to minimize confusion. As you become more familiar with the instructions, you will want to explore their full capabilities. These instructions are detailed in the *AdeptVision Reference Guide.*

Physical vs. Virtual Cameras

AdeptVision VXL allows you to establish several virtual cameras for each of your physical cameras (as long as the total number of virtual cameras does not exceed 32). One of the most important things you will learn in the next three chapters is how to control what a camera sees. You may find that you want to take several pictures of an object with each picture looking at the object in a different way. Virtual cameras allow you to do this. For example, you might want your first picture of an object to look at the perimeter shape and your second picture to look at interior features of the object. By establishing two virtual cameras for the physical camera looking at the object, you can take both types of pictures of the object. See "Why Use Virtual Cameras?" on page 54.

For the next two chapters, we assume your system has only one camera and that virtual camera 1 has been assigned to it. Therefore, all references to a camera mean *virtual and physical camera 1.*

The Point of Origin

Many of the operations you will be learning specify coordinate points within the field of view. These points will be given in Cartesian coordinates with the X/Y origin being at the lower left corner of the screen. This means that:

- In general, only positive numbers are meaningful. (When we introduce relative reference frames, negative values for tool placement are useful, but they must resolve to a positive value relative to the base vision reference frame.)
- The higher the number for the X coordinate, the further to the right on the screen the point is.
- The higher the number for the Y coordinate, the higher on the screen the point is.

These coordinates are in millimeters that refer to the actual distances in the field of view, not the dimensions of the monitor. This coordinate frame is referred to as the Vision Coordinate System. Tools placed relative to this coordinate system are in "vision coordinates".

> **NOTE:** The V$^+$ instructions GTYPE, GARC, etc., have their own coordinate system that is based in screen pixels with the coordinate frame origin at the top left of the vision window. The program instruction GTRANS will automatically convert real-world millimeters to screen pixels so you can specify millimeters for the "G" graphics instructions. The example program on page 221 shows how to use the GTRANS program instruction.

VPICTURE—Getting an Image

The VPICTURE operation (VPICTURE is both a monitor command and a program instruction) accomplishes two primary tasks:

- Acquires an image—gets the camera to transfer an electronic image to the controller
- Processes that image—using the software to filter the image data and gather information about the image

When a VPICTURE operation is performed, the vision system acquires an image into an image buffer. If the processing option has been selected, the image data is examined and basic image data is calculated. Depending on the setting of various vision switches described later in this chapter, the level of data gathered can be controlled. Each time a new VPICTURE is issued, the previous image data is overwritten.[1]

The results of a VPICTURE operation can be displayed in several different ways. The way an image is displayed depends on the selection made from the **Display** menu or with the VDISPLAY command (described in the next section).

VPICTURE Syntax

VPICTURE can be executed either from the monitor prompt or from within a vision program. The simplified VPICTURE syntax is:

```
VPICTURE(cam.virt) mode
```

`cam.virt`	is replaced with the number of the virtual camera you want to take a picture with. Camera 1 is the default value.
`mode`	is replaced with:

–1 indicating that a new image should be acquired and processed immediately. This is the default value.

2 indicating that a quick frame grab should be made and boundary analysis and prototype recognition should not be performed.

---

[1] See the full description of VPICTURE in the *AdeptVision Reference Guide* for details on storing multiple images.

VPICTURE Examples

Acquire an image with virtual camera 3 and process it immediately:

```
VPICTURE(3)
```

Acquire an image with virtual camera 3 and hold it for later processing (quick frame grab):

```
VPICTURE(3) 2
```

Executing VPICTURE From the Menu

To execute a VPICTURE command from the menu:

1. Pull down the **Cam/Frame** menu and drag to the number of the camera you want to take a picture with (only the first 8 virtual cameras can be selected from the menu).
2. Pull down the **Pict** menu and drag to the mode you want the picture taken in. The results will be shown in the vision window.

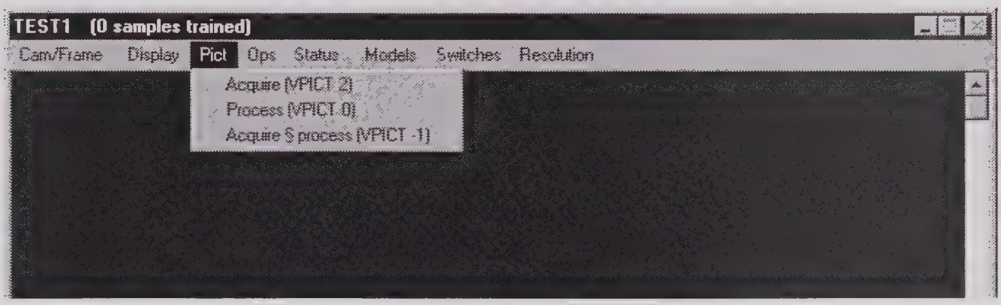

TEST1 (0 samples trained)
Cam/Frame
Display
Pict
Ops
Status
Models
Switches
Resolution
Acquire (VPICT 2)
Process (VPICT 0)
Acquire & process (VPICT -1)

Figure 8-1. VPICTURE Options

VDISPLAY—Displaying the Image

AdeptVision VXL provides several ways of displaying an acquired image on the screen. You choose a display mode depending on what image characteristics you are interested in, how time-critical your application is, and what information you want relayed to an operator.

VDISPLAY Syntax

VDISPLAY is both a monitor command and a program instruction. The simplified VDISPLAY syntax is:

```
VDISPLAY mode, overlay
```

`mode` is replaced with:

- –1 indicating a live grayscale image is to be displayed. This mode displays a live video image that shows you exactly what the camera currently sees (not the last picture that was acquired).
- 0 indicating a live thresholded (binary) image is to be displayed.
- 1 indicating that an acquired grayscale image is to be displayed. (Modes 1 to 4 take effect at the first VPICTURE after VDISPLAY is changed.)
- 2 indicating that an acquired binary or edge image is to be displayed.
- 3 indicating that a graphical representation of a processed image, along with any user-generated graphics, is to be displayed.
- 4 indicating that user-generated graphics should not be erased each time VPICTURE is executed. This mode is useful for graphs or data you want to display continuously.

`overlay` (used with "**`mode`**" = –1, 0, 1, and 2 only) is replaced with:

- 0 indicating no user graphics are to be overlaid. This is the default value.
- 1 indicating that any user- or system-generated graphics are to be overlaid on a frozen or live image (**`modes`** –1, 0, 1, and 2). (In **`modes`** 3 and 4, user-generated graphics are automatically displayed.)
- 2 indicating user graphics are to be displayed and not erased during successive VPICTURE operations.

VDISPLAY Examples

Display a live grayscale image with any user-generated graphics overlaid:

```
VDISPLAY -1,1
```

Display a graphical representation of the image, including user-generated graphics:

```
VDISPLAY 3
```

Executing VDISPLAY From the Menu

Pull down the **Display** menu and select the display mode you want to use. If you select any of the live or frame modes and want a graphics overlay, pull down the menu again and select an overlay. A "✔" indicates the option is selected.

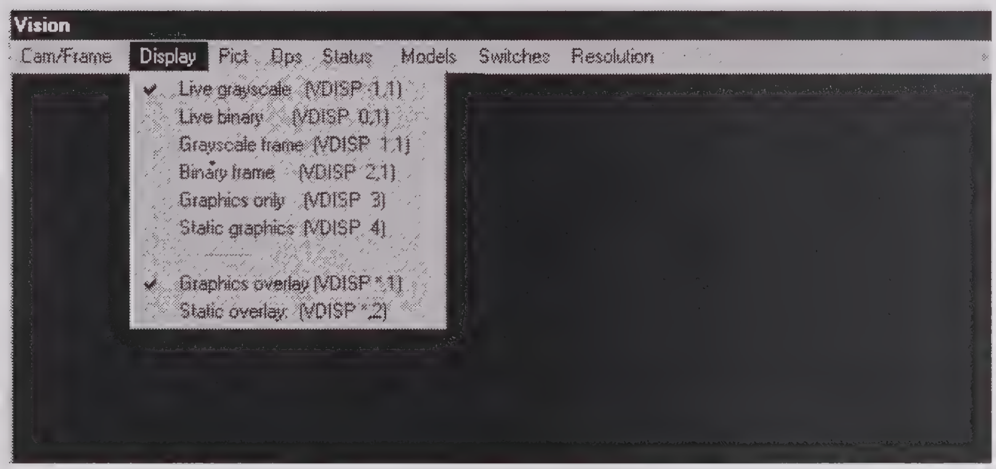

Vision
Cam/Frame
Display
Pict
Ops
Status
Models
Switches
Resolution
✔ Live grayscale [VDISP -1,1]
Live binary [VDISP 0,1]
Grayscale frame [VDISP 1,1]
Binary frame [VDISP 2,1]
Graphics only [VDISP 3]
Static graphics [VDISP 4]
✔ Graphics overlay [VDISP *,1]
Static overlay [VDISP *,2]

Figure 8-2. Display Mode Options

Using the Different Display Modes

Live Modes

Use the live modes for setting up your vision cell. These modes allow you to immediately see the effects of changes to:

- Camera lens focus
- Camera lens aperture
- Lighting
- Objects in the field of view
- Changes to parameters such as gain, offset, and threshold

Frame (Frozen) Modes

An acquired image in a frame store is referred to as a "frozen" image. Use the frozen modes to see the actual image the system is currently working with.

Graphics Mode

The live and frozen modes do not show you the actual edges the system has detected or the graphics that represent the vision tools. To see the processed image, use display mode 3. To see the tool graphics, use a graphics or graphics overlay mode.

Remember, displaying graphics requires processing time and is not essential to many vision operations. If your application is time critical, consider not displaying graphics.

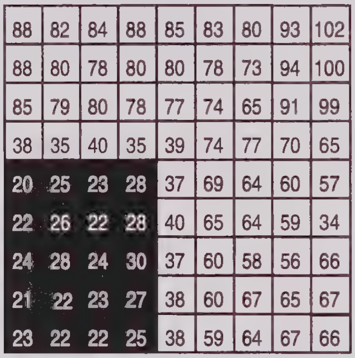
Binary vs. Grayscale Operations

To understand the relative advantages of grayscale and binary operations, it helps to understand what information the camera returns to the controller and how the controller interprets that information. Figure 8-3 shows a magnified section of an array of pixels that might be returned by a camera. In each pixel of the matrix is the grayscale intensity value the camera has registered from the field of view.

88	82	84	88	85	83	80	93	102
88	80	78	80	80	78	73	94	100
85	79	80	78	77	74	65	91	99
38	35	40	35	39	74	77	70	65
20	25	23	28	37	69	64	60	57
22	26	22	28	40	65	64	59	34
24	28	24	30	37	60	58	56	66
21	22	23	27	38	60	67	65	67
23	22	22	25	38	59	64	67	66

Figure 8-3. Sample Vision Matrix

When AdeptVision VXL creates a binary image, each value in the matrix is compared with a "threshold" value. All the pixels with a value above the threshold are considered white and all the pixels below this value are considered black. Figure 8-4 shows the binary image that would result from Figure 8-3 using a threshold value of 32. A binary line finder tool[1] would be able to find two lines in this image, the bottom and right edges (assuming the left and bottom edges represent the edge of the field of view).



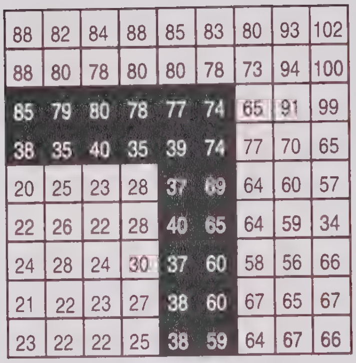
88	82	84	88	85	83	80	93	102
88	80	78	80	80	78	73	94	100
85	79	80	78	77	74	65	91	99
38	35	40	35	39	74	77	70	65
20	25	23	28	37	69	64	60	57
22	26	22	28	40	65	64	59	34
24	28	24	30	37	60	58	56	66
21	22	23	27	38	60	67	65	67
23	22	22	25	38	59	64	67	66

Figure 8-4. Binary Representation of Sample Matrix

When grayscale vision tools are used, the software processes image data based on the difference in intensity values found in the neighboring pixels. If the difference found exceeds an "edge strength value", the system considers the three-by-three area to be part of an edge. Figure 8-5 shows the four edges a grayscale line finder could find if an edge strength value of 20 were applied to the image data from Figure 8-3. (This illustration is somewhat idealized to help illustrate the point.)

---

[1] Line finders are described in Chapter 10.



88	82	84	88	85	83	80	93	102
88	80	78	80	80	78	73	94	100
85	79	80	78	77	74	65	91	99
38	35	40	35	39	74	77	70	65
20	25	23	28	37	69	64	60	57
22	26	22	28	40	65	64	59	34
24	28	24	30	37	60	58	56	66
21	22	23	27	38	60	67	65	67
23	22	22	25	38	59	64	67	66

Figure 8-5. Grayscale Representation of Sample Matrix

By comparing these three figures we can make several generalizations about grayscale vs. binary operations.

1. Binary operations use edge data based on only two states, black or white. Grayscale operations use edge data based on values in the range 0-127. Grayscale operations examine 3 x 3 sections of pixels when calculating edges. This means binary operations will require less processing time.
2. Binary operations look for edges based on an absolute intensity value. This means that if the overall brightness of the image changes, binary operations may see the image differently (the edges will move based on the increasing or decreasing brightness of the image). Grayscale operations look for the relative difference between intensity values in an image. Thus, if the overall brightness changes, the relative brightness should remain similar and the system will see edges in the same place. In general, grayscale operations will be less affected by ambient lighting changes than will binary operations.
3. Since grayscale operations look for intensity differences, you will be able to identify edges that occur in more than one brightness range. In the examples above, if there had been an intensity change in the range of 80 to 110, binary operations would have considered the entire area to be white and ignored the change. Grayscale operations would have perceived the intensity difference and calculated an edge.

   In the case of an object with several interior features, grayscale operations may be the only way to recognize interior features. You may find, when inspecting a part, that the interior features are not of interest and need to be filtered out, in which case binary operations might be more appropriate.

Some additional considerations when deciding whether to use grayscale or binary operations are:

1. A few AdeptVision VXL tools can operate only on binary data. These will be described in the following chapters.
2. All of the grayscale tools can be used even when the picture is processed with binary operations.
3. Grayscale tools can be more accurate than binary tools. Grayscale tools use an algorithm that potentially allows them to locate features with subpixel accuracy.

Each time an image is acquired, both grayscale and binary data are stored. When making a decision about the type of operation to use, you are not limited to one or the other. You can inspect an image using binary and grayscale operations, making use of the unique features of each to make different inspections of the image.

Switches and Parameters

Before you can begin using the vision tools to inspect objects, you need to acquire a clear, accurate image that displays the features you are interested in and filters out features you are not interested in. AdeptVision VXL has two classes of system variables that control the way it sees objects and what information the system will gather about those objects. The two classes of variables are switches and parameters.

When an image is processed, the effects of the switches and parameters are reflected in the data returned by the vision system. For example, suppose you have a part that has several 6 mm and 13 mm holes, but you are interested only in the 13 mm holes. By setting a combination of switches and parameters you can acquire an image that processes data about the 13 mm holes and ignores the 6 mm holes.

During the development of your applications, care should be taken to set the switches and parameters so that your system produces clear images and processes only the minimum detail needed to accomplish the desired vision task (processing unneeded data consumes processing time and may slow your applications).

All switches and parameters can be set within a program. This allows you to set the variables for one image, take a picture, process the data, and then change the variables for the next picture or image. Remember, each virtual camera has its own arrays of switches and parameters. This allows you to use different virtual cameras to take pictures using different parameter, switch, and calibration settings, while using the same physical camera.

The switches and parameters can be broken into three main functional groups. The first group influences the way the system initially acquires the image. This group will be presented in this section.

The second group influences the types of processing the system performs and what information it gathers about the objects it finds in the field of view. This group will be presented in **Chapter 9**.

The third group influences the model recognition processes. This group will be presented in **Chapter 11**.

The entire group of switches and parameters is listed in **Appendix A**.

Using Switches

Switches are software variables that can take on a binary value—they are either on or off. Switches are referred to as being enabled or disabled. There is an array of switch settings for each virtual camera.

Enabling/Disabling Switches

Switches are set using the ENABLE and DISABLE monitor commands or program instructions. Their syntax is:

```
ENABLE switch[camera],...,switch[camera]
```

```
DISABLE switch[camera],...,switch[camera]
```

switch	is replaced with any of the switches listed in Table 8-1 (or Appendix A).
camera	is replaced with the number of the virtual camera you want to set the switch for. The default value is *all* cameras. If you are using multiple cameras with different switch/parameter settings, make sure you include a camera number in each switch.[1]

These switches can be set by pulling down the **Switches** menu in the vision window, dragging to the switch you want to change, and releasing the mouse button. A "✔" next to the switch name indicates that the switch is enabled. The switch settings apply to whichever camera is selected in the **Cam/Frame** menu.

The current state of a switch can be read within a program with the SWITCH( ) function.

Viewing Switch Settings

To see the status of all system switches, issue the command SWITCH from the system prompt. To see the status of the switches from the vision window menu, pull down the **Switches** menu. Switches marked with a "✔" are enabled.

---

[1] This argument applies only to vision switches and parameters. V^+ system switches and parameters do not require this argument.

SWITCH Example

The following example will enable the binary switch for virtual camera 4 and then output its current state:

```
ENABLE V.RECOGNITION[4]
IF SWITCH(V.RECOGNITION[4]) THEN
  TYPE "V.RECOGNITION[4] is ON"
ELSE
  TYPE "V.RECOGNITION[4] is OFF"
END
```

Image-Acquisition Switches

Table 8-1 provides a brief description of the switches that affect the way the system sees an object. "Switches and Parameters Used During Boundary Analysis" on page 136 describes the switches that influence what information the system gathers about an object. Complete information on each switch is available in the *AdeptVision Reference Guide*. Appendix A summarizes all the switches available to AdeptVision VXL.

Table 8-1. Image-Acquisition Switches

Switch	Effects
V.BINARY	If disabled, it will affect the operation of VPICTURE modes –1, 1, and 2 in the following ways: For VPICTURE modes 2 and 1, it will start a VEDGE operation immediately following the completed acquisition into the virtual frame buffer. For VPICTURE mode –1, a VEDGE operation is performed prior to processing of the image. In this case, the VPICTURE instruction will not complete until after the first stage of processing (the computation of run-lengths) is complete. Therefore, the run-lengths are computed on the binary edge image which is the result of VEDGE (see Appendix B in the *AdeptVision Reference Guide* for details on how vision run-lengths are generated). In each case above, the choice of edge operation to be performed (cross-gradient or Sobel) is determined by the value of the system parameter V.EDGE.TYPE. And the edge strength threshold is given by the V.EDGE.STRENGTH system parameter.
V.BACKLIGHT	The system has no way of differentiating between background and object unless you tell it which one is dark and which one is light. This switch tells the system which intensity is background and which intensity is object. If the switch is set incorrectly, the system will process the background rather than the object. Disable the switch for a dark background and enable it for a light background. (Applies to binary processing only.)
V.BOUNDARIES	Enables or disables boundary analysis. If this switch is disabled, perimeter, edge, centroid, 2nd moment data, and hole data will not be gathered. This switch *must be enabled* for prototype recognition and OCR.

Using Parameters

Parameters affect the vision system in much the same way switches do, except that parameters can take on a range of values—not just on or off.

Setting Parameters

Parameters are set by entering the monitor command program instruction:

```
PARAMETER param_name[cam.virt] = value
```

param_name is replaced with the name of the parameter you want to set.

`cam.virt`	is replaced with the virtual camera number you want to set the parameter for. The default is *all* cameras. If you are using multiple cameras with different parameter settings, make sure you include a camera number with each PARAMETER command.
value	is replaced with the new value you want the parameter to have.

Parameter Examples

Output the entire parameter list to the screen:[1]

```
PARAMETER
```

Display the value of a single parameter (V.THRESHOLD for example):

```
PARAMETER V.THRESHOLD
```

To return the value of a parameter from within a program, use the PARAMETER function:

```
TYPE "V.THRESHOLD is: ", PARAMETER(V.THRESHOLD[1])
```

Image-Acquisition Parameters

Table 8-2 describes briefly the parameters that primarily influence how AdeptVision VXL sees regions in the field of view. Complete information on each parameter is available in the *AdeptVision Reference Guide*. Appendix A gives a brief description of all the parameters available to AdeptVision VXL.

---

[1] The parameter DISP.CAMERA determines how many virtual cameras will have their arrays of switches and parameters displayed.

Table 8-2. Image-Acquisition Parameters

Parameter	**Effects**
V.FIRST.COL	Sets the first column (in pixels) that will be processed by the system. Used to speed processing time by ignoring unwanted areas to the left side of the field of view. Must be less than or equal to V.LAST.COL. (Note: the effect of the first four parameters in this list is generally ignored by vision tools that use the "area-of-interest" option. See **"Defining a Tool Area-of-Interest (AOI)" on page 146** for details.)
V.FIRST.LINE	Sets the first line (in pixels) that the system will process. Everything below this line will remain unprocessed. Must be less than or equal to V.LAST.LINE.
V.LAST.COL	Sets the last column (in pixels) that will be processed. Everything to the right of this column will remain unprocessed. Must be greater than or equal to V.FIRST.COL.
V.LAST.LINE	Sets the last line (in pixels) that will be processed. Everything above this line will remain unprocessed. Must be greater than or equal to V.FIRST.LINE.
V.MAX.AREA	Sets a value for the largest object (in pixels) the system will process. Useful if a large object is in the same field of view as the object you are interested in. The setting of V.SUBTRACT.HOLES affects this parameter. Must be greater than or equal to V.MIN.AREA.
V.MIN.AREA	Sets a value for the smallest object the system will attempt to process. Useful for ignoring small objects you are not interested in and filtering out noise. Must be greater than or equal to V.MIN.HOLE.AREA and less than or equal to V.MAX.AREA. The setting of V.SUBTRACT.HOLES is considered when comparing area values.
V.MIN.HOLE.AREA	Sets a value for the smallest hole (in pixels) in an object that the system will process. Must be less than or equal to V.MIN.AREA.
V.THRESHOLD	Sets the intensity at which the system divides pixels into black or white.
V.2ND.THRESHOLD	Used with V.THRESHOLD to establish a range of intensity that the system will see as black or white. For example, with V.THRESHOLD at 50 and 2ND.THRESHOLD at 70, all pixels between 50 and 70 would be seen as black.
V.EDGE.STRENGTH	Sets the threshold at which the system recognizes an edge in grayscale processing. If the variation in pixel intensity across a region exceeds this parameter, an edge is recognized.
V.GAIN	AdeptVision VXL recognizes 128 degrees of intensity. V.GAIN works with V.OFFSET to maximize the use of these 128 values. V.GAIN scales the incoming analog video signal.
V.OFFSET	Works with V.GAIN to maximize the range of intensities that the system recognizes in your objects. V.OFFSET is applied to the incoming video signal.

Examples of Switch and Parameter Settings

The examples in this section show the effects of changing switches and parameters. The examples were taken with a VPICTURE ( ) –1 instruction and with VDISPLAY mode set to 3.

> **NOTE:** These examples allow you to see the effects of various switch and parameter settings. For V$^+$ programs, it is recommended that you use the vision program instructions such as VWINDOW in place of V.FIRST.COL, V.FIRST.LINE, etc., and VEDGE in place of V.BINARY. These vision tools will provide a more modular approach for your programs

Figure 8-6 shows the object that is being placed in the field of view. This is the sample object that was introduced in Chapter 1.

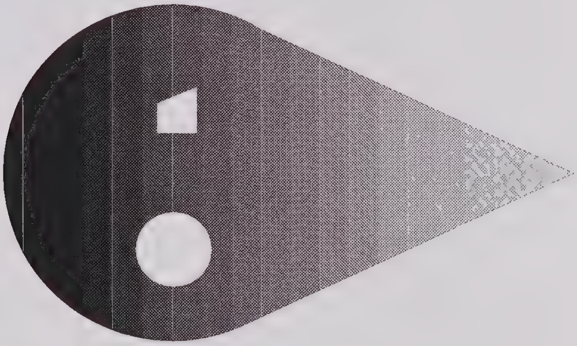


Figure 8-6. Sample Object

One of the first things you will notice about VDISPLAY mode 3 is that the object is rendered in white and the background in black, regardless of the actual intensities of the object and background.

In Switch and Parameter Example 1, the switches and parameters are set to obtain the best possible image. This image was obtained with the following switch and parameter settings:

Switches					
✓	V.BINARY	✓	V.BOUNDARIES	✓	V.BACKLIGHT
Parameters					
1	V.FIRST.COL	1	V.FIRST.LINE	640	V.LAST.COL
480	V.LAST.LINE	307,200	V.MAX.AREA	16	V.MIN.AREA
100	V.OFFSET	90	V.GAIN	8	V.MIN.HOLE.AREA
55	V.THRESHOLD	0	V.2ND.THRESH	20	V.EDGE.STRENGTH

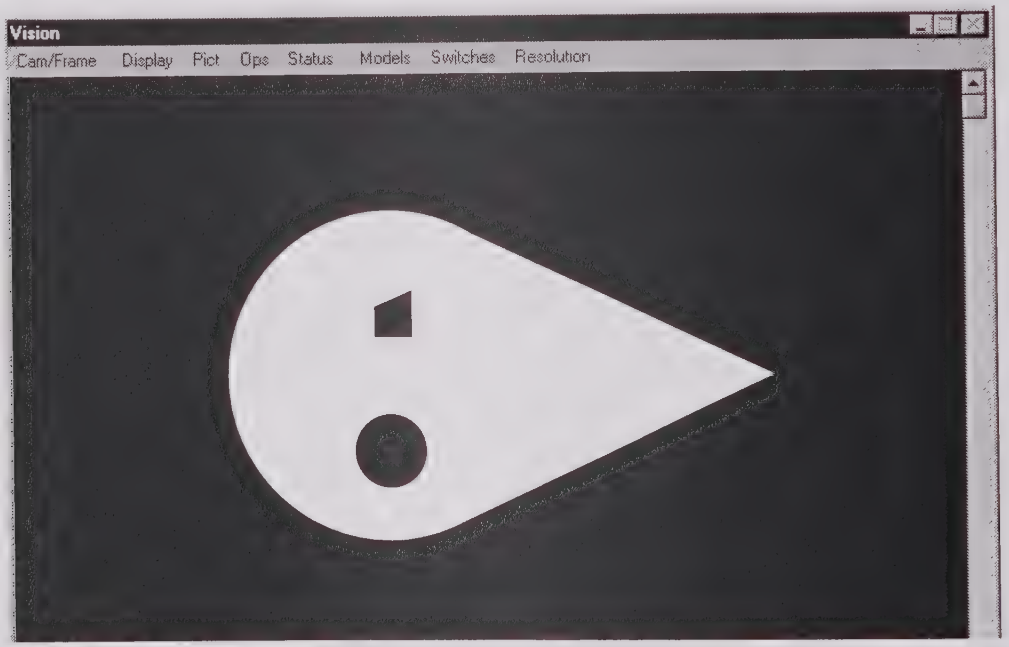


Figure 8-7. Switch and Parameter Example 1

In the following examples, the switches or parameters that have been changed are marked with a shadow.

> **NOTE:** If you are experimenting with the sample object, remember that parameter settings are sensitive to ambient lighting. Therefore, your parameter settings may be different to obtain the same image.

In Switch and Parameter Example 2, V.BINARY is disabled, resulting in an edge image. When the system processes this image, it will operate on the edges generated using the parameter V.EDGE.STRENGTH rather than the binary image generated using the parameter V.THRESHOLD.

The settings for **Switch and Parameter Example 2** are:

Switches					
	V.BINARY	✓	V.BOUNDARIES	✓	V.BACKLIGHT
Parameters					
1	V.FIRST.COL	1	V.FIRST.LINE	640	V.LAST.COL
480	V.LAST.LINE	307,200	V.MAX.AREA	16	V.MIN.AREA
100	V.OFFSET	90	V.GAIN	8	V.MIN.HOLE.AREA
55	V.THRESHOLD	0	V.2ND.THRESH	20	V.EDGE.STRENGTH

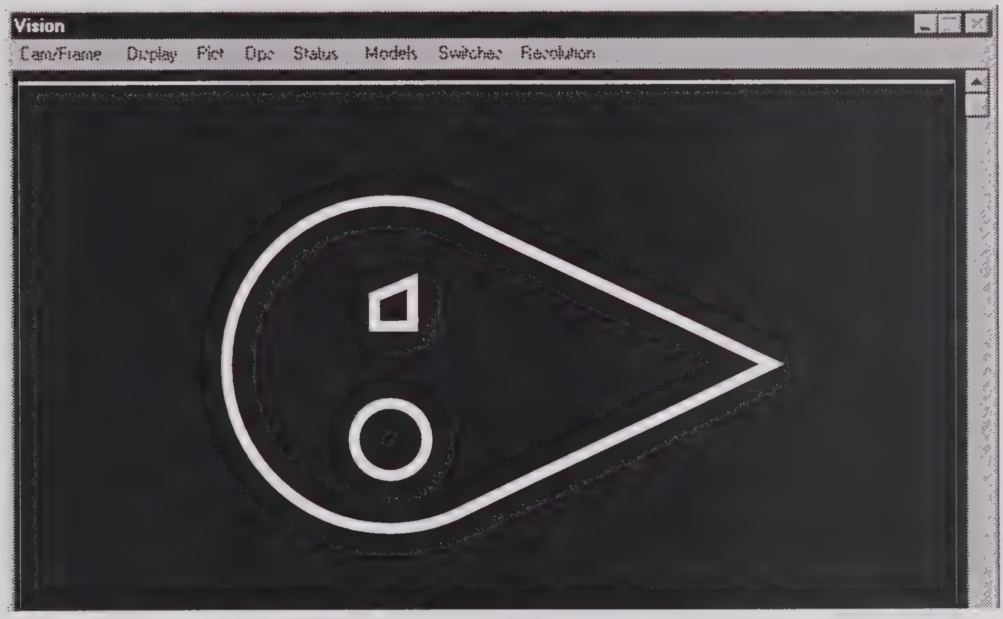


Figure 8-8. Switch and Parameter Example 2

Changing the value of V.EDGE.STRENGTH to 40 causes the system to fail to recognize an edge at the tail end of the object. The change in intensity values at the tail of the object does not exceed the value of V.EDGE.STRENGTH so edges are not detected in that area. **Switch and Parameter Example 3** shows the effects of changing this parameter.

The settings for **Switch and Parameter Example 3** are:

Switches					
	V.BINARY	✓	V.BOUNDARIES	✓	V.BACKLIGHT
Parameters					
1	V.FIRST.COL	1	V.FIRST.LINE	640	V.LAST.COL
480	V.LAST.LINE	307,200	V.MAX.AREA	16	V.MIN.AREA
100	V.OFFSET	90	V.GAIN	8	V.MIN.HOLE.AREA
55	V.THRESHOLD	0	V.2ND.THRESH	40	V.EDGE.STRENGTH

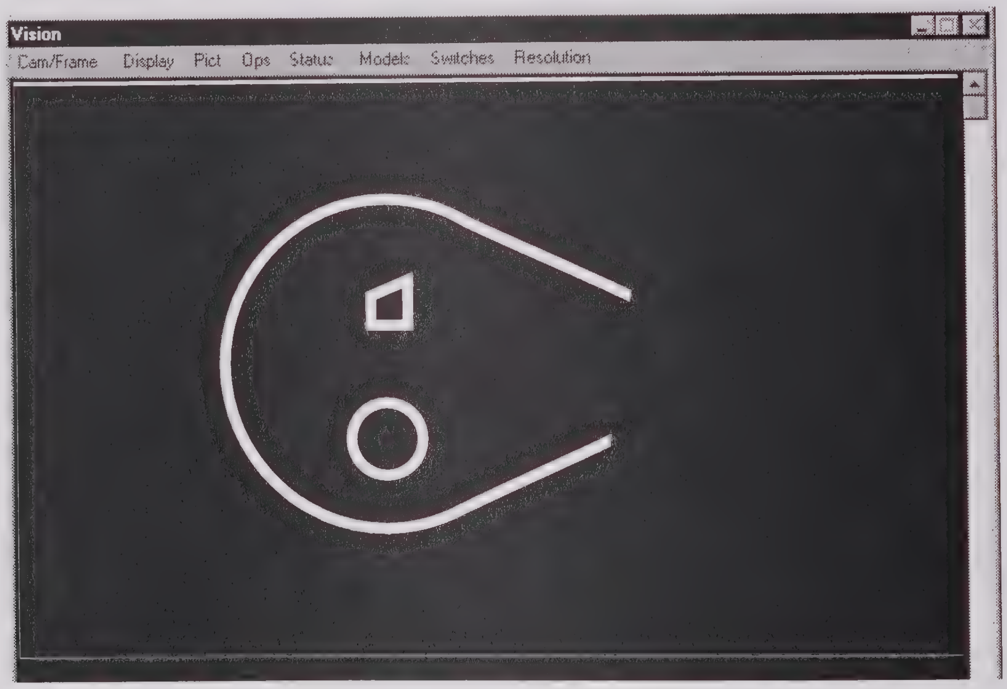


Figure 8-9. Switch and Parameter Example 3

If the small polygon in the object is not of interest to you, instruct the system to ignore it by changing the value of the minimum hole size the system will process within an object. (V.MIN.AREA will have to be raised to a value greater than V.MIN.HOLE.AREA.) **Switch and Parameter Example 4** shows the effects of changing these two parameters. Raising these two parameters further would cause the circular hole to be ignored.[1] (V.BINARY has been reenabled for this example.)

The settings for **Switch and Parameter Example 4** are:

Switches					
✔	V.BINARY	✔	V.BOUNDARIES	✔	V.BACKLIGHT
Parameters					
1	V.FIRST.COL	1	V.FIRST.LINE	640	V.LAST.COL
480	V.LAST.LINE	307,200	V.MAX.AREA	650	V.MIN.AREA
100	V.OFFSET	90	V.GAIN	625	V.MIN.HOLE.AREA
55	V.THRESHOLD	0	V.2ND.THRESH	20	V.EDGE.STRENGTH

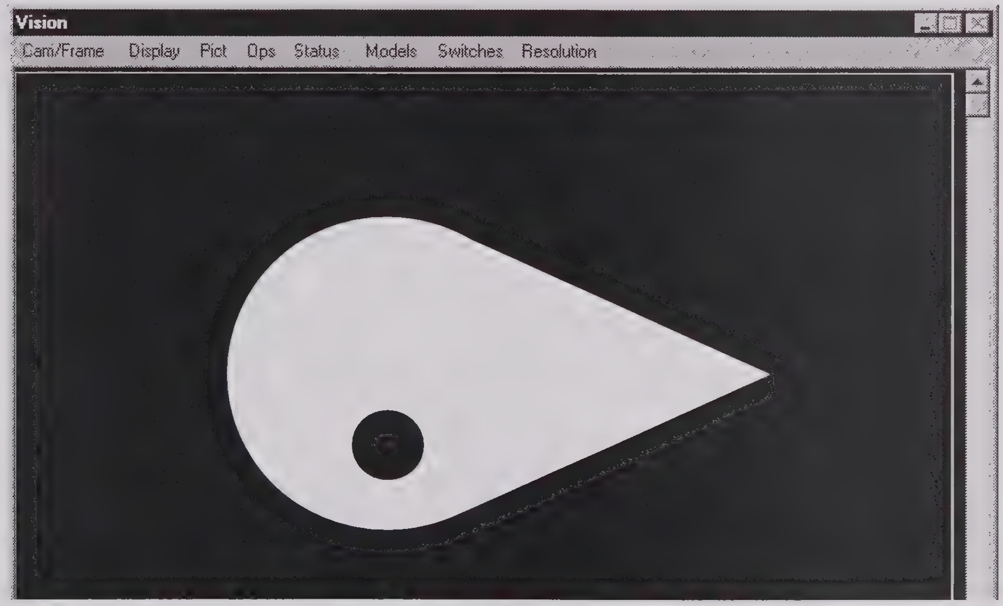

Vision
Cam/Frame
Display
Pict
Ops
Status
Models
Switches
Resolution

Figure 8-10. Switch and Parameter Example 4

---

[1] These two values could be raised high enough to cause the system to ignore the object completely.

The effects of changing V.THRESHOLD are shown in **Switch and Parameter Example 5**. We have lowered the threshold value to the point where the system does not see a sufficiently high intensity in the pixels at the tail end of the object to consider them part of the object. Therefore, they are considered background, and an image like the one in "Switch and Parameter Example 5" is produced. (Note that changing V.THRESHOLD for a binary image is similar to changing V.EDGE.STRENGTH for a gray-edge image — see "Switch and Parameter Example 3".)

The settings for **Switch and Parameter Example 5** are:

Switches					
✓	V.BINARY	✓	V.BOUNDARIES	✓	V.BACKLIGHT
Parameters					
1	V.FIRST.COL	1	V.FIRST.LINE	640	V.LAST.COL
480	V.LAST.LINE	307,200	V.MAX.AREA	16	V.MIN.AREA
100	V.OFFSET	90	V.GAIN	8	V.MIN.HOLE.AREA
20	V.THRESHOLD	0	V.2ND.THRESH	20	V.EDGE.STRENGTH

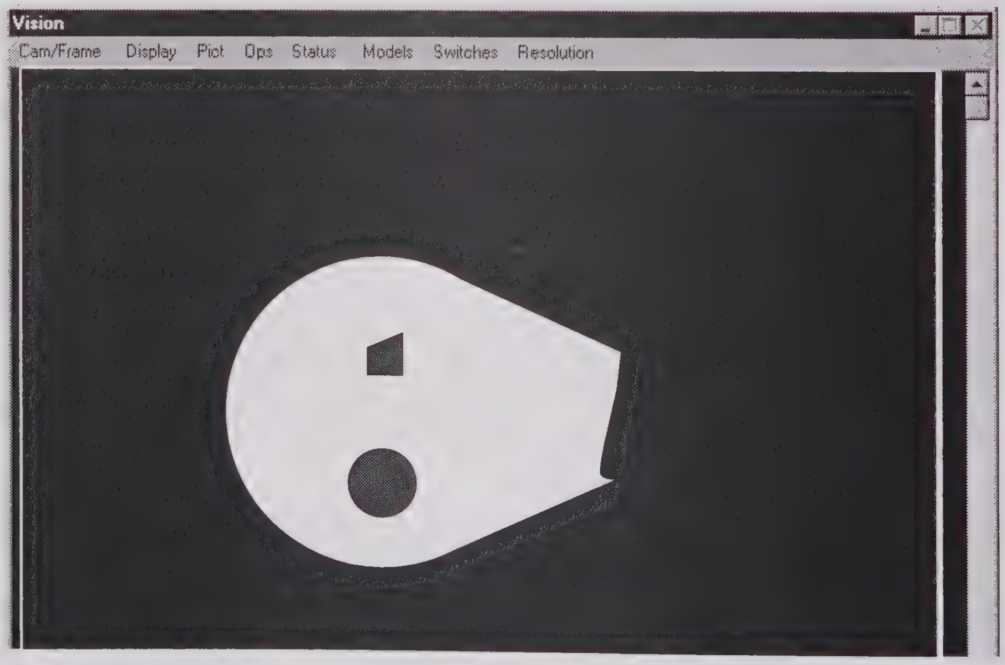


Figure 8-11. Switch and Parameter Example 5

You can limit the field-of-view area that is processed by changing the parameters that specify the starting and ending columns and rows of pixels to process. This is useful if you are interested in only a small area of the field of view, or if a portion of the field of view needs to be blocked off because it interferes with processing the area you are interested in. Switch and Parameter Example 6 shows how to limit the processed area. Remember, line settings are measured from the bottom of the screen, and column settings are measured from the left side. These parameters apply only to the VPICTURE and VWINDOW instructions. The areas-of-interest defined for the various vision tools will override any processing boundaries set with V.FIRST.COL, V.LAST.COL, etc.

The settings for **Switch and Parameter Example 6** are:

Switches					
✔	V.BINARY	✔	V.BOUNDARIES	✔	V.BACKLIGHT
Parameters					
150	V.FIRST.COL	200	V.FIRST.LINE	360	V.LAST.COL
350	V.LAST.LINE	307,200	V.MAX.AREA	16	V.MIN.AREA
100	V.OFFSET	90	V.GAIN	8	V.MIN.HOLE.AREA
55	V.THRESHOLD	0	V.2ND.THRESH	20	V.EDGE.STRENGTH

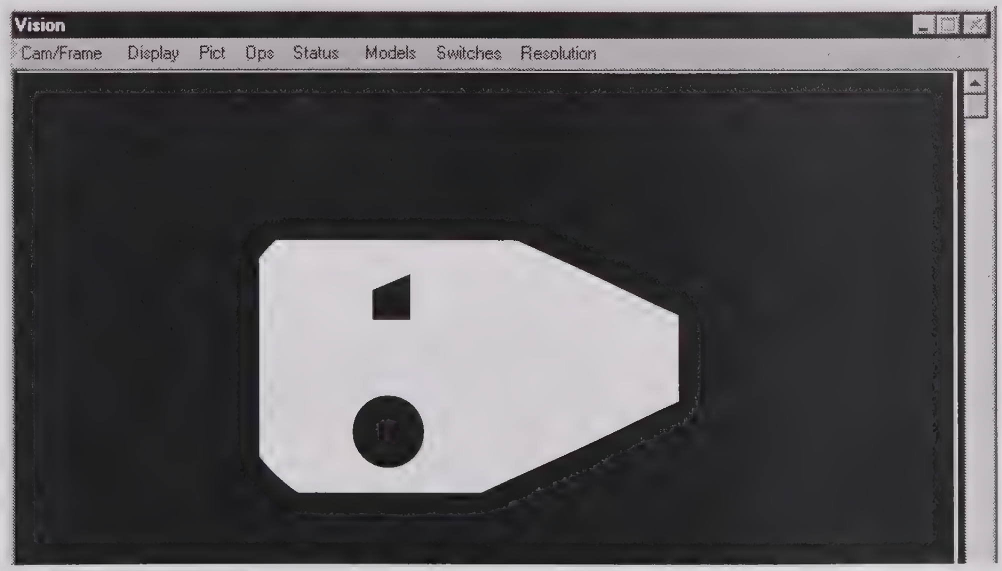


Figure 8-12. Switch and Parameter Example 6

Switch and Parameter Example 7 shows the effect of disabling V.BACKLIGHT. What we have told the system is that we now have light objects on a dark background. This causes the system to consider areas of darkest intensity as background. In the image below, the processor considers the object to be the background and vice versa. (Remember, in VDISPLAY mode 3, the object is rendered as white and the background as black.) If your vision operation examines white labels on a black conveyor belt, you will disable this switch. You may also find that some inspections can be made more easily when the background/object intensities are reversed.

The settings for **Switch and Parameter Example 7** are:

Switches					
✔	V.BINARY	✔	V.BOUNDARIES		V.BACKLIGHT
Parameters					
1	V.FIRST.COL	1	V.FIRST.LINE	640	V.LAST.COL
480	V.LAST.LINE	307,200	V.MAX.AREA	16	V.MIN.AREA
100	V.OFFSET	90	V.GAIN	8	V.MIN.HOLE.AREA
55	V.THRESHOLD	0	V.2ND.THRESH	20	V.EDGE.STRENGTH

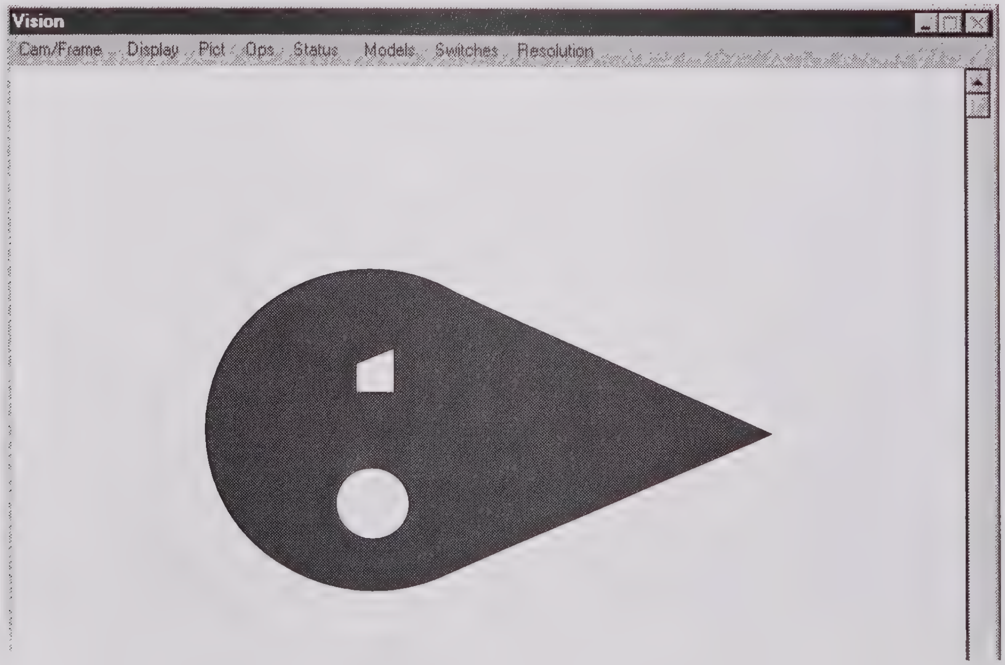


Figure 8-13. Switch and Parameter Example 7

Boundary Analysis

9

Introduction . . . 136

  Switches and Parameters Used During Boundary Analysis . . . 136

Boundary Analysis Instructions . . . 138

  VLOCATE . . . 138
    VLOCATE Examples . . . 139
  The DO Monitor Command . . . 140
  VFEATURE . . . 140
    What is VFEATURE? . . . 140
    Blob Allocation . . . 142
    VFEATURE Example . . . 142
  VQUEUE . . . 143

Introduction

Now that you know how to acquire and process an image, this chapter will show you how to get some useful information from that image. This chapter covers the first information processing strategy that AdeptVision VXL employs, boundary analysis (often called "blob analysis").

Chapter 10 covers the second strategy, vision tools, and Chapter 11 covers the third information processing strategy, vision model processing.

When the system processes an image, it explores the boundaries of all the regions in the field of view and stores the information it gathers about each of those regions in a special vision queue. Two operations are required to retrieve boundary information. The first is VLOCATE, which retrieves a region's data from the vision queue. The second operation, VFEATURE, retrieves individual data items. In many cases this data will tell you all you need to know about an object: You will not have to use any other vision tools or model processing.

Before we look at VLOCATE and VFEATURE let's examine the switches and parameters that influence their performance.

Switches and Parameters Used During Boundary Analysis

In addition to the switches and parameter listed below, all the switches and parameters introduced in Chapter 8 affect VLOCATE and VFEATURE. For example, one piece of information available through VFEATURE is the number of holes in a region. If we set the parameter V.MIN.HOLE.AREA so that it was larger than the size of the two holes in our sample object (see Example 4 on page 131), then VFEATURE will report that there are 0 holes in the sample object.

The switches and parameters listed in Table 9-1 and Table 9-2 determine what data (and in some cases, the form of the data) the system gathers during boundary analysis of the regions within the processed image.

Table 9-1. Boundary Analysis Switches

Switch	Effects
V.BOUNDARIES	Enables or disables boundary processing. If this switch is disabled, perimeter, edge, centroid, 2nd moment data, and hole data will not be gathered. Must be enabled for vision model processing.
V.SUBTRACT.HOLE	When this switch is enabled, the area of holes within an object will be subtracted from the area calculation. This switch affects the parameters V.MIN.AREA, V.MAX.AREA, and V.MIN.HOLE.AREA.

Table 9-1. Boundary Analysis Switches (Continued)

Switch	Effects
V.CENTROID	The centroid of an object is calculated if this switch is enabled. This switch increases processing time and should be disabled if the centroid information is not needed. (V.BOUNDARIES must be enabled.)
V.MIN.MAX.RADII	The perimeter points closest to and farthest from the centroid of an object are calculated when this switch is enabled. (V.BOUNDARIES and V.CENTROID must be enabled.)
V.2ND.MOMENT	The 2nd moments of inertia and best fit ellipse are calculated when this switch is enabled (V.CENTROID and V.BOUNDARIES must be enabled). V.SUBTRACT.HOLES is ignored.
V.PERIMETER	The perimeter of an object is calculated if this switch is enabled.
V.HOLES	If this switch is enabled, the statistics gathered for objects will also be gathered for the holes in the objects.
V.SHOW.EDGES	If this switch is enabled, the vision system will display the attempts at fitting primitive edges to an object.
V.SHOW.BOUNDS	If this switch is enabled, the vision system will display the results of attempting to fit lines and arcs during boundary analysis. This switch is useful during development as it allows you to see how the vision processor performs boundary analysis.
V.FIT.ARCS	Enabling this switch causes the system to attempt arc fitting during boundary analysis. If arcs are unimportant in your images, processing time will be improved by disabling this switch.

Table 9-2. Boundary Analysis Parameter

Parameter	Default	Range		Effects
V.MAX.PIXEL.VAR	1.5	0	8	Sets the maximum pixel variation allowed when the system fits a line or an arc to a region boundary.

Boundary Analysis Instructions

In order to make boundary analysis data available, you must:

- Enable the system switch V.BOUNDARIES (along with any other switches required for the data you are interested in).
- Acquire a processed image using VPICTURE. (You can also acquire an unprocessed image and then use a VWINDOW instruction to process a limited area of the image. This procedure is described in "Processing Windows (VWINDOW)" on page 164.)
- Remove a region's data from the vision queue and make it available to VFEATURE using the VLOCATE instruction.
- Use VFEATURE to return the particular information you are interested in.

We have already seen the syntax for VPICTURE and how to set system switches. This section will describe VLOCATE and VFEATURE, and describe the VQUEUE instruction that allows you to see the status of the vision queue.

VLOCATE

When an image is processed, each region's data is stored in a queue. If V.HOLES is enabled, the data about the holes in each object is also stored in this queue. To use the data, you must remove it from the queue and make it available to VFEATURE. The VLOCATE program instruction performs this operation.

> **NOTE:** This instruction supports the ObjectFinder tool. Except where noted, the usage is the same as for prototypes.

The syntax for VLOCATE is:

```
VLOCATE (camera, mode, order) $var_name, trans_var
```

`camera`	is replaced with the camera from whose vision queue you wish to remove an object. (There is a queue of data for *each* virtual camera.) The default is camera 0, which makes the contents of the queues of all virtual cameras available.
`mode`	is replaced with:[1]
	0 causing the system to attempt to remove a region's data from the queue (referred to as "locating a region"). 0 is the default.

---

[1] See the *AdeptVision Reference Guide* for details on default values for `mode` and `order`.

4 causing the system to attempt to remove a hole's data from the vision queue. (V.HOLES must be enabled. Hole data is available only for holes in the most recently VLOCATEd region.)

NOTE: The mode parameter is not available when using VLOCATE with the ObjectFinder tool.

`order`	is replaced with:[1]

1 causing the system to remove objects from the queue starting with the largest object.

2 causing the system to remove objects from the queue starting with the smallest object.

NOTE: Only the bounding box values are available when using VLOCATE with the ObjectFinder tool.

`$var_name`	To remove an unrecognized region (known as a "blob") from the queue, replace "`$var_name`" with **"?"**. To remove a hole's data (`mode` = 4) leave this parameter blank. (Until we cover prototype recognition in **Chapter 11**, all regions will be unrecognized and **"?"** will be used for "`$var_name`".)
`trans_var`	Optional transformation variable to be assigned the location of the object.

The type of model being supported is determined by the name, which has been trained as either a prototype or an ObjectFinder model. The name is checked against the lists of prototypes first for backward compatibility. Therefore, you should not use the same name for a prototype model and an ObjectFinder model.

VLOCATE Examples

If a successful VPICTURE instruction has acquired and processed an image with at least one region in it, the instruction:

```
VLOCATE (1, 0) $name, trans_var
```

will locate any object in the queue and make its region data available through VFEATURE( ). (If the object is recognized as a prototype, the prototype name will be returned.)

If the region located had at least one hole in it, the command:

```
VLOCATE (1,4)
```

---

[1] See the *AdeptVision Reference Guide* for details on default values for `mode` and `order`.

will locate the first hole in the most recently VLOCATEd region and make its region data available through VFEATURE( ). For a hole to be located, V:HOLES must have been enabled when the image was processed.

The DO Monitor Command

Most of the V^+ operations covered in the rest of this manual are program instructions and do not have a monitor command format. Program instructions can be executed only from within a program and not directly from the system prompt. If you want to experiment with various program instructions without writing and executing a program, you can preface a program instruction with the monitor command DO and execute it from the system prompt. For example, to execute VLOCATE from the system prompt, enter the command:

```
DO VLOCATE (1,2) "?"
```

VFEATURE

Once an image has been acquired and processed with a VPICTURE instruction, and a region or a hole in a region has been removed from the queue with a VLOCATE instruction, data on that object is available through use of the function VFEATURE.

> **NOTE:** VFEATURE supports the ObjectFinder tool. Except where noted, the usage is the same as for prototypes.

What is VFEATURE?

VFEATURE is not a monitor command or a program instruction. It is a system function that returns a value. As such, it can be used in most places you would use a variable. For example:

```
IF VFEATURE(10) > 975 THEN...
```

or

```
part_centerx = VFEATURE(42)
```

(A critical point to remember when using VFEATURE is that it is a function that returns a value and not an array of values. You cannot assign a value to a VFEATURE index. For example, the instruction VFEATURE(12) = 3.303 would produce an error.)

Table 9-3 lists the values available through VFEATURE as a result of boundary analysis. Additional data is available after prototype recognition; this is covered in Chapter 11. The complete VFEATURE table is printed in Appendix B.

Table 9-3. VFEATURE Values and Interpretation

Index	**Information**	**Unit**	**Switch/Parameter effects**
1	Whether an object was found or not (true/false)	T/F	Returns –1 for true or 0 for false.
2	Center X	mm	If V.CENTROID is enabled, the value is the centroid of the region. Otherwise, it is the center of the bounding box of the region.
3	Center Y	mm	
4	Center Z	mm	
5	Rotation about X	°	
6	Rotation about Y	°	
7	Rotation about Z	°	
10	Area of object	pixels	If V.SUBTRACT.HOLES is enabled, the area of holes in the object is subtracted from this calculation.
11-12	ID numbers	#	See the description of VFEATURE in the *AdeptVision Reference Guide* for details on these two items.
13	Left limit of region's bounding box	mm	
14	Right limit of region's bounding box	mm	
15	Lower limit of region's bounding box	mm	
16	Upper limit of region's bounding box	mm	
17	Number of holes in the object	#	
18	Time spent acquiring, processing, and recognizing an object	secs	
21	When an object is located, all the holes within the object are given a reference number. This value is the reference number of the current hole. (Also holds true for "holes within holes.")	#	Holes can be located within a bounded region or within a hole in a bounded region. These values keep track of where you are in the locating sequence. Holes are number consecutively for each region.
22	Parent number of holes referenced in VFEATURE(21)	#	
40	Total area of all holes	pixels	V.HOLES must be enabled.
41	Outer perimeter of the object	mm	V.PERIMETER must be enabled.
42	Object centroid along X axis	mm	V.CENTROID must be enabled.
43	Object centroid along Y axis	mm	

Table 9-3. VFEATURE Values and Interpretation (Continued)

Index	Information	Unit	Switch/Parameter effects
44	The angle (relative to the vision coordinate system) of a line drawn to the closest point on the object perimeter from the centroid	°	V.CENTROID and V.MIN.MAX.RADII must be enabled.
45	The angle of a line drawn to the farthest point on the object perimeter from the centroid	°	
46	The shortest distance from an object's centroid to a point on its perimeter	mm	
47	The greatest distance from an object's centroid to a point on its perimeter	mm	V.CENTROID and V.MIN.MAX.RADII must be enabled.
48	The angle of the object's major axis (axis of least inertia)	°	V.CENTROID and V.2ND.MOMENTS must be enabled.
49	Major radius of the ellipse [along the axis reported in VFEATURE(48)]	mm	
50	Minor radius of the ellipse [perpendicular to the axis reported in V.FEATURE(48)]	mm	

Blob Allocation

The number of blobs that can be stored in the various vision queues is dependent on vision memory. AdeptVision VXL sets the maximum vision memory that can be used by the vision queues, as well as other objects that reside in vision memory. This default allocation can be changed to suit your particular application with the DEVICE instruction. Appendix J lists the default allocations and how to change them.

VFEATURE Example

Here is an example of boundary analysis using the values returned by VFEATURE. If we wanted to know the perimeter of our sample object, the number of holes in that object, and the center of the circular hole, the following program code would provide that information:

```
; Display the results of the next VPICTURE instruction in graphics mode

   cam.virt = 1

   VDISPLAY (cam.virt) 3

; Make sure hole information is gathered
```

```
    ENABLE V.HOLES [cam.virt]
    ENABLE V.BOUNDARIES [cam.virt]
    DISABLE V.DISJOINT [cam.virt]
    ENABLE V.CENTROID [cam.virt]

; Make sure perimeter information is gathered

    ENABLE V.PERIMETER

; Acquire and process an image

    VPICTURE (cam.virt) -1

; Remove any object from the queue for "cam.virt"

    VLOCATE (cam.virt) $name, trans_var

; Check for a successful VLOCATE (i.e., an object was found)

    IF VFEATURE(1) THEN

; Display the perimeter of the object and the number of holes

        TYPE "Object perimeter is: ", VFEATURE(41)
        TYPE "The number of holes in the object is: ", VFEATURE(17)

; Locate the largest hole in the object

        VLOCATE (cam.virt, 4, 1)

; Check for a successful VLOCATE

        IF VFEATURE(1) THEN

; Display the coordinates of the center hole

           TYPE "Center hole coordinates: ", VFEATURE(2), VFEATURE(3)
        END
    END
```

VQUEUE

The monitor command VQUEUE shows the status of the vision queue. The syntax for VQUEUE is:

```
VQUEUE (cam.virt)
```

`cam.virt`	is replaced with the camera number whose queue you wish to examine. The default is 0, indicating all cameras.

When you execute a VQUEUE command, you will see a display similar to:

```
Name     Verify     Area      X       Y      RZ    Instance  Camera
         percent                                      ID
?          0.0    177797   182.3   80.7   0.00       1         1
?          0.0      2904   151.7   89.0   0.00       2         1
aproto    85.4     36855   159.1   85.9   8.70       3         1
```

Name	If a region has been recognized as a prototype, its name will appear in this column. Otherwise a "?" will appear indicating that information on an unidentified region ("blob") has been placed in the queue.
Verify percent	A measure of how confident prototype recognition is.
Area	Area of the region in raw pixels.
X, Y, RZ	Region transformation components (position and rotation in the vision coordinate system).
Instance ID	Order of processing for the different objects (an arbitrary but sometimes useful ID number).
Camera	Camera the image was acquired with.

To determine the number of items remaining in a queue from within a program, use the real-valued function VQUEUE( ). The following code will remove objects from the vision queue for virtual camera 4 (if the 4 is omitted, the code will look through all queues):

```
WHILE VQUEUE(4) DO
  VLOCATE(4)

  ; code executed for each region

  TYPE "Number of objects left: ", VQUEUE(4)
END
```

Vision Tools 10

Defining a Tool Area-of-Interest (AOI) 146
    Frame Stores 146
        Virtual Frame Buffers 146
    Areas-of-Interest 147
        Defining an Image Buffer Region 149
Linear Rulers 152
    VRULERI Array 152
    Linear Ruler Example 153
Arc Rulers 155
    Arc Ruler Example 155
Ruler Types 158
    Standard Binary Rulers (type = 0) 158
    Raw Binary Rulers (type = −1) 158
    Dynamic Binary Rulers (type = −2) 158
    Graylevel Rulers (type = 1) 159
    Fine Edge/Fine Pitch Rulers (type = 2/3) 159
        Ruler Speed and Accuracy 160
Finder Tools 160
    VFIND.LINE Array 161
    Line Finder Tool Polarity 161
    VFIND.LINE Example 162
Processing Windows (VWINDOW) 164
    VWINDOW Example 164
Vision Tools: Inspection Windows (VWINDOWI) 165
Vision Tool Data Arrays 165
Windows, Windows, Windows 166

Defining a Tool Area-of-Interest (AOI)

Vision tools operate within a specified area-of-interest. Since several different tools may be placed in the same area, AdeptVision VXL allows you to predefine areas-of-interest. These areas-of-interest can then be used by multiple tools. Also, as we will see in Chapter 14, tools may be placed relative to reference frames generated by other tools. An area-of-interest definition allows you to easily reposition groups of tools based on new image data.

An AOI is a relative Cartesian reference that must be combined with an absolute origin point before it can be used. (The AOI also includes shape and orientation components.) The absolute origin to which an AOI is relative is a "virtual frame buffer". When you combine an AOI with a virtual frame buffer you get an "image buffer region" that identifies the exact size, shape, orientation, and location for a vision tool.

Frame Stores

A vision system has two physical frame stores. These physical frame stores are numbered 1 and 2. For the standard vision processor, the frame store size is 1024 x 512 pixels. Systems with the AdeptVision Enhanced VXL Interface option have 1024 x 1024 frame stores. This frame size can be further divided into virtual frame buffers as described next. Any frame store area not used as a virtual frame buffer is used as a "scratch" area for tools such as Correlation Templates.

Virtual Frame Buffers

The standard vision system can be divided into 2, 4, 12, or 16 virtual frame buffers. A system configured for 2 virtual frame buffers uses one 640 x 480 virtual frame buffer area in each physical frame store. A system configured for 4 frame stores uses two 512 x 480 virtual frame buffers in each physical frame store. A system configured for 12 frame stores uses six 360 x 240 virtual frame buffers in each physical frame store. And a system configured for 16 frame stores uses eight 256 x 240 virtual frame buffers in each physical frame store.

On systems with the AdeptVision Enhanced VXL Interface option, the physical frame stores are twice as large so they may be divided into twice as many virtual frame buffers (four 640 x 480 virtual frame buffers—two for each physical frame store, etc.).

The DEVICE instruction allocates virtual frame buffers. See "Example: Changing the Number of Virtual Frame Stores" on page 323 for details. Figure 10-4 shows how physical frame stores are divided in the virtual frame buffers.

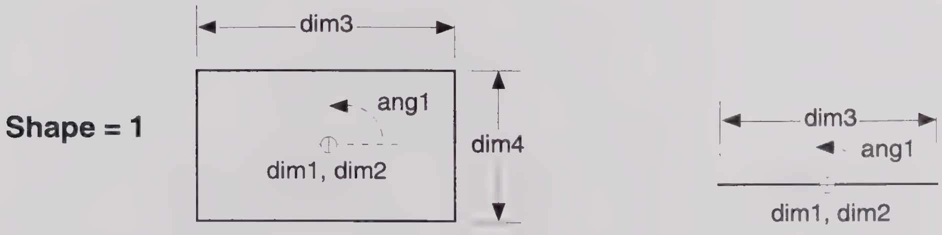
Areas-of-Interest

Vision tools are placed within a virtual frame buffer based on a defined area-of-interest (AOI). AOIs are defined with the VDEF.AOI instruction and include a shape argument and several dimensional arguments. The syntax for VDEF.AOI is:

`VDEF.AOI aoi = shape, dim1, dim2, dim3,` `dim4, ang1, ang2`

`aoi`	an integer that identifies the AOI being defined. This value must be a 4- to 6-digit integer. Counting from least significant to most significant (right to left), the fourth through sixth digits are used as the AOI number and the first through third digits are ignored. See "Defining an Image Buffer Region" on page 149 for details on how the first through third digits are used.
`shape`	defines the shape of the area-of-interest. The most common shapes are shown in Figures 10-1 and 10-2. See the *AdeptVision Reference Guide* for a complete description of the shapes.
`dim1` - `dim4`	define the size and location of the area-of-interest.
`ang1, ang2`	define the angular measurements of the area-of-interest

Figure 10-1 shows the most common shapes for rectangular tools. Shape 1 is the normal shape for rectangular areas such as windows, line finders, point finders, etc. Shape 2 is the normal shape for rulers.[1] Figure 10-2 shows the most common shapes for arc-shaped tools. Shape 5 is the normal shape for arc finders, and shape 9 is the normal shape for circular inspection windows.



---

[1] The illustration shows a shape with a positive value for `dim3`. Negative values are allowed, in which case dim1 and dim2 will be on the opposite side of the rectangle.

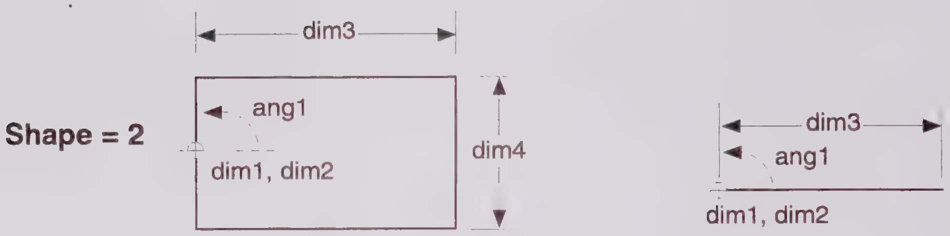

Shape = 2
dim3
ang1
dim1, dim2
dim4
dim3
ang1
dim1, dim2

Figure 10-1. Rectangular Area-of-Interest Shapes

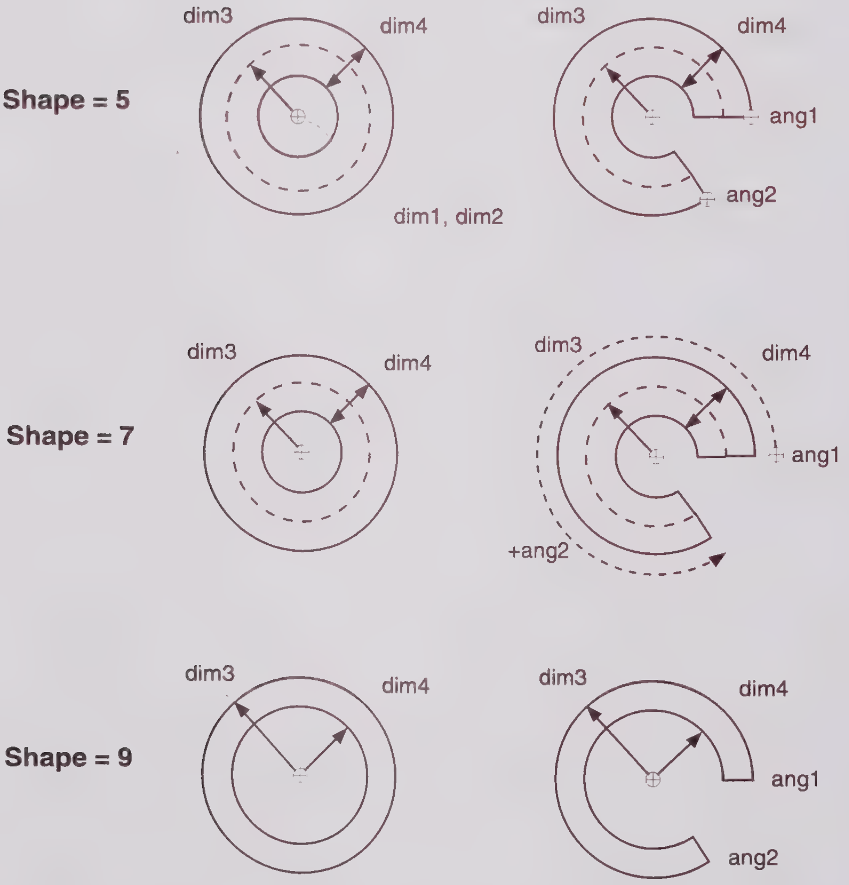

Shape = 5
dim3
dim4
dim1, dim2
dim3
dim4
ang1
ang2
Shape = 7
dim3
dim4
dim3
dim4
ang1
+ang2
Shape = 9
dim3
dim4
dim3
dim4
ang1
ang2

Figure 10-2. Arc-Shaped Area-of-Interest Shapes

Defining an Image Buffer Region

A image buffer region has the form:

```
AAAVVP
```

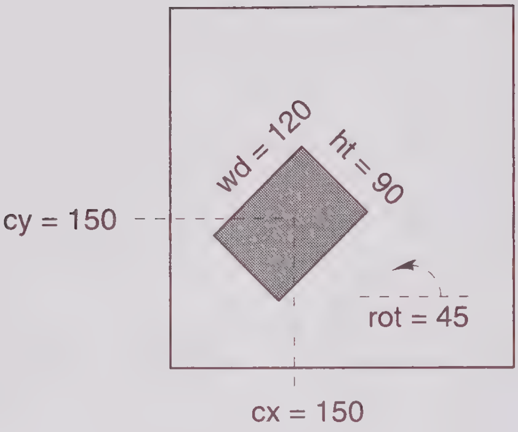
where "AAA" is the number of the area-of-interest (defined byVDEF.AOI), "VV" is the virtual frame buffer, and "P" is the number of the physical frame store. The combination of virtual frame store and a physical frame store creates a "virtual frame buffer", which is the term most often used in Adept documentation.

If 000 is specified for the virtual frame buffer, the most recently acquired picture is used. Thus, a virtual frame buffer needs to be specified only when you want to place a tool in an image other than the one most recently acquired.

The next program example defines "aoi12"—a rectangular AOI that is centered at X = 150mm, Y = 150mm; is 90mm wide and 120mm high; and is rotated 45°.

```
shape = 1
cx = 150
cy = 150
wd = 120
ht = 90
rot = 45
aoi12 = 12000
VDEF.AOI aoi12 = shape, cx, cy, wd, ht, rot
```

Figure 10-3 shows the area-of-interest defined by the preceding code. The program example that follows the figure defines an image buffer region that uses "aoi12".



VDEF.AOI 12000 = 1, 150, 150, 120, 90, 45

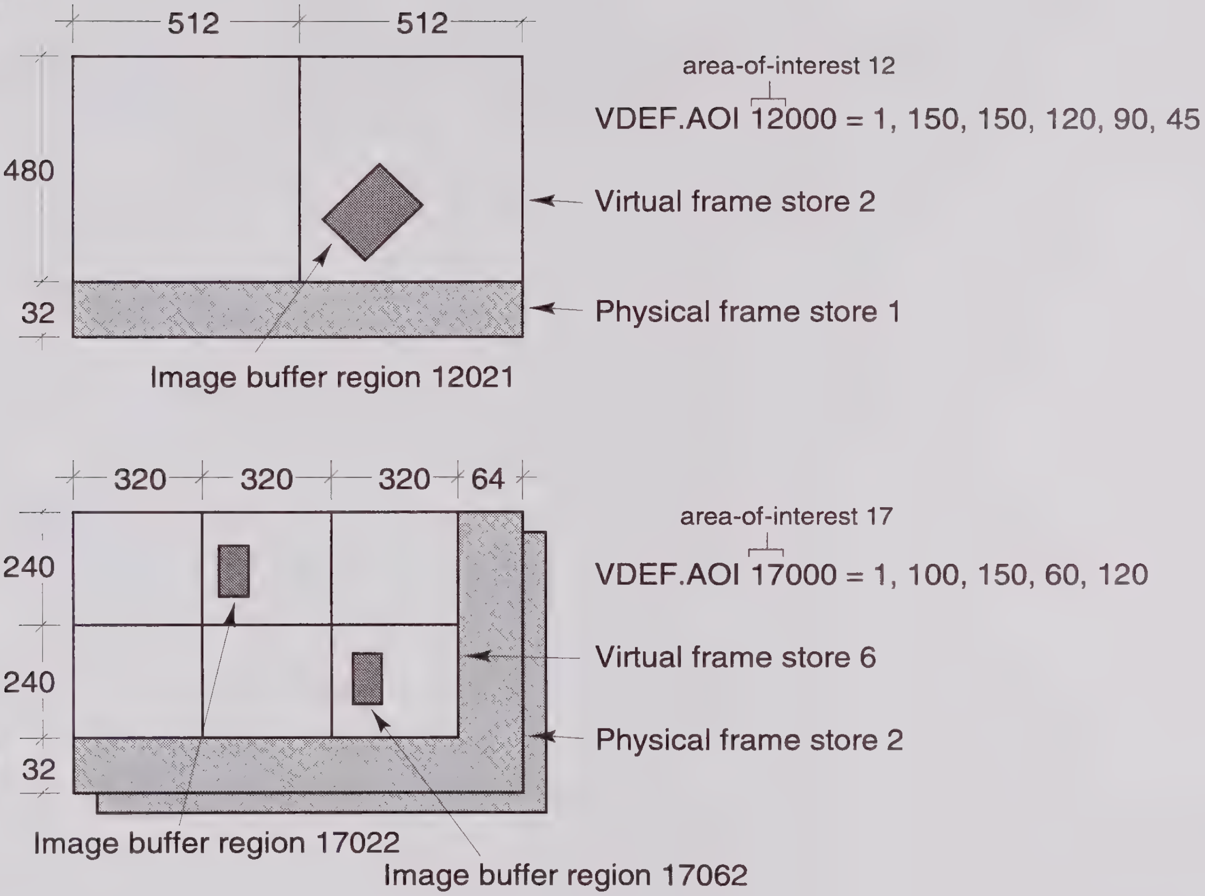
Figure 10-3. Sample Area-of-Interest

In order to use this AOI with a virtual frame buffer other than the one an image was most recently acquired into, it must identify a virtual frame buffer. The following code combines virtual frame buffer 21 with "aoi12" to create the image buffer region "ibr_rect":

```
phy.fr = 1
virt.fr = 20
ibr_rect = aoi12+virt.fr+phy.fr
```

"ibr_rect", which now has the value 12021, can be used by any rectangular or line-shaped tool that needs to be placed at the defined location in virtual frame buffer 21. The first example in Figure 10-4 shows the definition of "ibr_rect". (The example assumes a mm/pixel ratio of 1.)

The second example in Figure 10-4 shows how an AOI definition can be combined with different virtual frame buffers to create different image buffer regions.



```
VDEF.AOI 12000 = 1, 150, 150, 120, 90, 45
VDEF.AOI 17000 = 1, 100, 150, 60, 120
```

512
512
480
32
area-of-interest 12
Virtual frame store 2
Physical frame store 1
Image buffer region 12021
320
320
320
64
240
240
32
area-of-interest 17
Virtual frame store 6
Physical frame store 2
Image buffer region 17022
Image buffer region 17062

Figure 10-4. Sample Image Buffer Regions

Linear Rulers

Linear rulers are vision tools that detect edges found along the length of the ruler and return the distances from the start of the ruler. Linear rulers can operate on binary or grayscale data, regardless of the setting of V.BINARY.

The simplified syntax for a linear VRULERI is:

```
VRULERI (cam.virt, type) data[] = ibr
```

`cam.virt`	is replaced with the number of a virtual camera. The value of V.EDGE.STRENGTH associated with this virtual camera will be used by some of the ruler types (see **"Ruler Types" on page 158**). The value of V.THRESHOLD is used with dynamic binary rulers. The default value is camera 1.
`type`	is replaced with the type of ruler you want to place on the image. The default value is 0, indicating a run-length binary ruler. The different types of rulers are explained in **"Ruler Types" on page 158**.
`data[]`	is replaced with a variable name for the array into which you want the ruler data placed (see VRULERI array below).
`ibr`	is replaced with the number of a defined image buffer region specifying a rectangular AOI (see **"Defining a Tool Area-of-Interest (AOI)" on page 146**).

VRULERI Array

When you have issued a VRULERI command, the edge transition data is placed in the array you specified. The element values are:

data[0]	The number of edges found along the ruler.
data[1]	For binary rulers, the color of the pixel the ruler started on. For grayscale rulers, whether or not the ruler was clipped by the field of view.
data[2]	The distance from the starting point to the first transition.
data[3]	The distance from the starting point to the second transition.
data[n]	The distance from the starting point to the (n–1)th transition.

Linear Ruler Example

This example code takes a picture of the sample object and reports how far it is from the round hole in the object to the left edge of the object, measured along the X axis. We start similarly to the VFEATURE example shown in Chapter 9:

```
;Display the results of the next VPICTURE in live mode
; with a graphics overlay.

   cam.virt = 1

   VDISPLAY (cam.virt) -1, 1

;Make sure hole information is gathered.

   ENABLE V.HOLES [cam.virt]
   ENABLE V.BOUNDARIES [cam.virt]
   DISABLE V.DISJOINT [cam.virt]

;Acquire and process an image.

   VPICTURE (cam.virt) -1

;Locate any object (i.e, remove the object from the queue).

   VLOCATE (cam.virt) $name

;Locate the round hole in the object

   VLOCATE (cam.virt, 4, 1)

;Place a 50mm fine-edge linear ruler that starts at the center of the circular
; hole--VFEATURE(2) & VFEATURE(3)--and is rotated 180 deg with respect to the X
; axis. Place the ruler data in the array testdata[].

   VDEF.AOI 3000 = 2, VFEATURE(2), VFEATURE(3), 50, 0, 180
   VRULERI (cam.virt, 2) testdata[] = 3011;AOI 3, virt frame buffer 11

;Calculate the distance between the first and second transitions.

   dist_horz = testdata[3]-testdata[2]

;Display the result, dist_horz.

   TYPE "The distance is: ", dist_horz
```

Figure 10-5 illustrates the preceding code example.

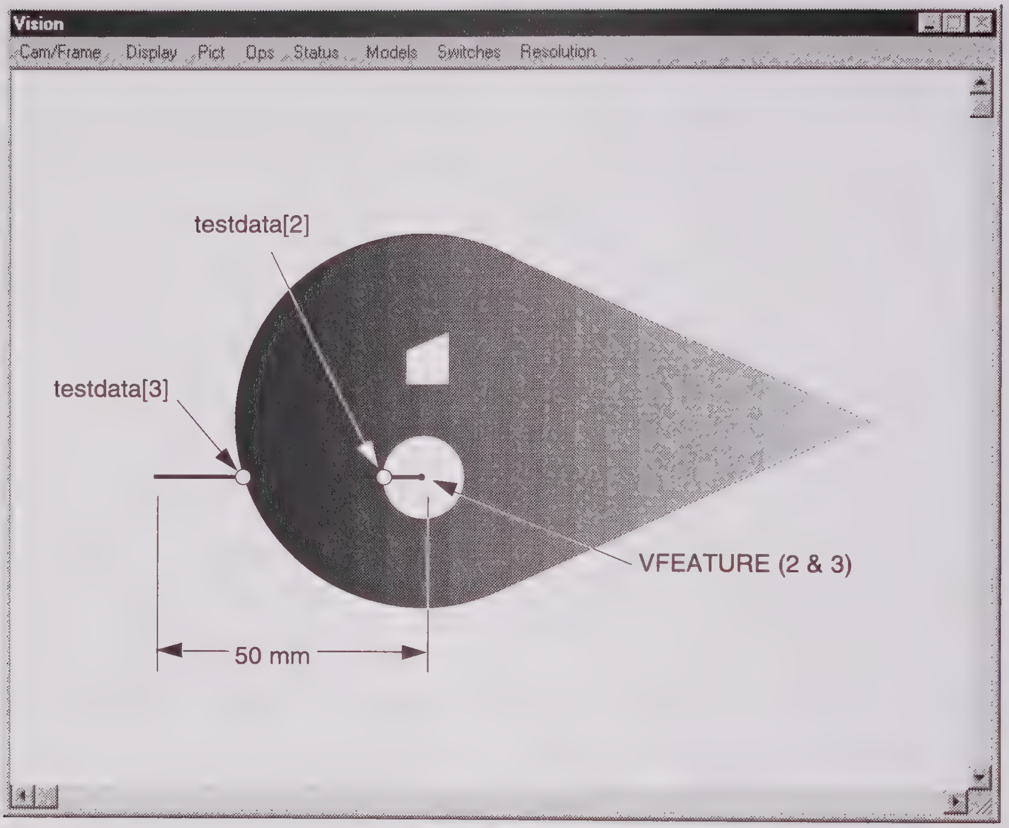

Vision
Cam/Frame Display Pict Ops Status Models Switches Resolution
testdata[2]
testdata[3]
VFEATURE (2 & 3)
50 mm

Figure 10-5. Linear Ruler Example

If (after executing the above code) you want to see all the values in the testdata array, issue this command:

```
LISTR¹ testdata[]
```

and the monitor window will display values similar to these:

```
testdata[0] = 2
testdata[1] = 1
testdata[2] = 5.15576
testdata[3] = 46.256
```

---

[1] LISTR is a monitor command that lists real variables resident in system memory.

Arc Rulers

In addition to linear rulers, AdeptVision VXL allows you to place circular and arc-shaped rulers. Arc rulers return the angular distance between edges found along an arc. These rulers are particularly useful for inspecting part features that are arranged radially around a part center. The syntax for an arc ruler is:

```
VRULERI(cam.virt, type) data[] = ibr
```

The parameters are the same as for a linear ruler, except the image buffer region must specify a circular AOI.

Arc Ruler Example

Let's examine the face of a circular gauge to see if the graduation marks are properly spaced. The gauge we will examine is shown in Figure 10-6. We will assume that we know the ideal angular distance between the centers of any two graduation marks. We will also assume that the hole for the gauge dial is correctly placed.

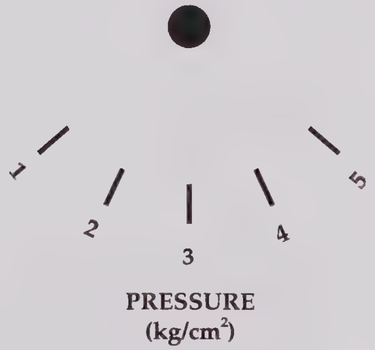


Figure 10-6. Sample Gauge Face

The code that would examine the gauge follows.

```
;Specify the pass-fail limits

   min_dist = 21
   max_dist = 23

;Display the results of the next VPICTURE in live mode
;with a graphics overlay.
```

```
    cam.virt = 1
    VDISPLAY (cam.virt) -1, 1

;Make sure hole information is gathered.

    ENABLE V.HOLES [cam.virt]
    ENABLE V.BOUNDARIES [cam.virt]
    DISABLE V.DISJOINT [cam.virt]
    ENABLE V.CENTROID [cam.virt]

;Set the minimum area parameters to filter "noise"

    PARAMETER V.MIN.AREA [cam.virt] = 60
    PARAMETER V.MIN.HOLE.AREA [cam.virt] = 50

;Acquire and process an image.

    VPICTURE (cam.virt) -1
    VWAIT

;Remove the largest object (the center hole) from the queue.

    VLOCATE (cam.virt, 2, 1) "?", gauge_center

;Check for successful VLOCATE

    IF NOT VFEATURE(1) THEN
        GOTO 100
    END

;Get the X/Y values of the gauge center

    centx = VFEATURE(2)
    centy = VFEATURE(3)

;Remove the topmost region from the queue.  This will be one of the
; graduation marks.

    VLOCATE (cam.virt, 2, 6) "?", mark_center

;Check for successful VLOCATE

    IF NOT VFEATURE(1) THEN
        GOTO 100
    END

;Use the function DISTANCE to calculate the distance from the center
; of the gauge to the center of a mark.

    arc_rad = DISTANCE(gauge_center,mark_center)

;Place an arc ruler
```

```
    VDEF.AOI 4000 = 7, centx, centy, arc_rad, 0, 170, 200
    VRULERI (cam.virt, 2) testdata[] = 4000

;Make sure the correct number of transitions were found

    IF testdata[0] <> 10 GOTO 100

;Print the inspection data

    FOR x = 3 TO 9 STEP 2
        act_dist = testdata[x+1]-testdata[x]
        pass = (act_dist > min_dist) AND (act_dist < max_dist)
        TYPE /S, "Distance from mark ", INT(x/2), " to mark "
           TYPE INT(x/2)+1, " is ", act_dist
           TYPE /S, "This inspection "
           IF pass THEN
               TYPE "passed."
           ELSE
               TYPE "failed."
           END
    END

  100 TYPE "No object found, program stopped."
```

Figure 10-7 shows the ruler and transition points resulting from the preceding code.[1]

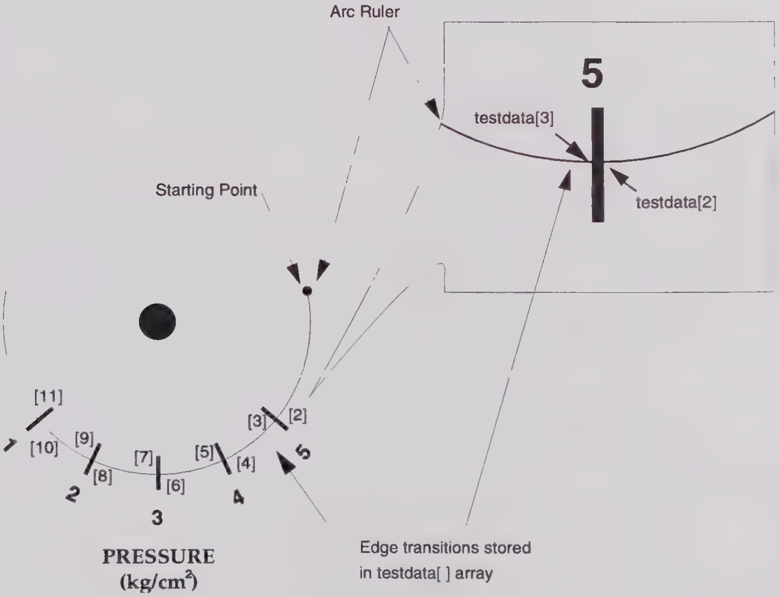

Arc Ruler
5
testdata[3]
testdata[2]
Starting Point
[11]
[10]
[9]
[8]
[7]
[6]
[5]
[4]
[3]
[2]
1
2
3
4
5
PRESSURE
(kg/cm²)
Edge transitions stored
in testdata[ ] array

Figure 10-7. Arc Ruler Example

---

[1] This example could have been simplified by using the VRULERI parameter that specifies transitions in only one direction (light-to-dark or dark-to-light)—see the *AdeptVision Reference Guide.*

Ruler Types

VRULERI provided us with the first example of a vision operation that can be performed on an unprocessed image (quick frame grab). There are several different types of rulers, some of which work on a processed image and some of which work on the raw grayscale or binary image.

The argument "`type`" determines which type of ruler will be used.

Standard Binary Rulers (*type* = 0)

This is the default ruler type (it is also referred to as the run-length binary ruler). It operates on processed image data (after VPICTURE in "*mode*" = –1, or within a VWINDOW processing window). The effects of most system parameters are taken into account by this type of ruler. (For example, if a ruler crosses a hole smaller than the size specified in V.MIN.HOLE.AREA, then it will not find the edges of the hole.) If V.BINARY is enabled, edges are found in a binary image. Otherwise, they are found in a binary edge image.

Raw Binary Rulers (*type* = –1)

This ruler operates on unprocessed data in the binary frame store. Most of the system parameters will be ignored by this ruler. If V.BINARY is enabled, edges are found in a binary image. Otherwise, they are found in a binary edge image.

Dynamic Binary Rulers (*type* = –2)

This ruler operates on data in the grayscale frame store. Edges are found based on the current value of V.THRESHOLD and V.2ND.THRESH (as opposed to the setting of these parameters when the image was acquired). As the ruler looks for edges in the grayscale frame store, the pixels it crosses are thresholded according to the current parameter setting (but the data in the frame stores is not changed). This ruler type allows you to specify different values for the threshold parameters for each ruler you place.

Graylevel Rulers (*type* = 1)

This ruler operates on the grayscale frame store. It returns the graylevel value of each pixel the ruler crosses. The values are placed in the `data[]` array. The first value in the array is the number of pixels found.

Fine Edge/Fine Pitch Rulers (*type* = 2/3)

These rulers operate on the grayscale frame store. They look for edges based on the setting of V.EDGE.STRENGTH. These rulers allow you to look for edges based on changes in intensity rather than binary thresholded values. Unlike other ruler types, these rulers find edges with subpixel accuracy. See the *AdeptVision Reference Guide* for more details.

Figure 10-8 shows a comparison of standard binary and raw binary rulers.

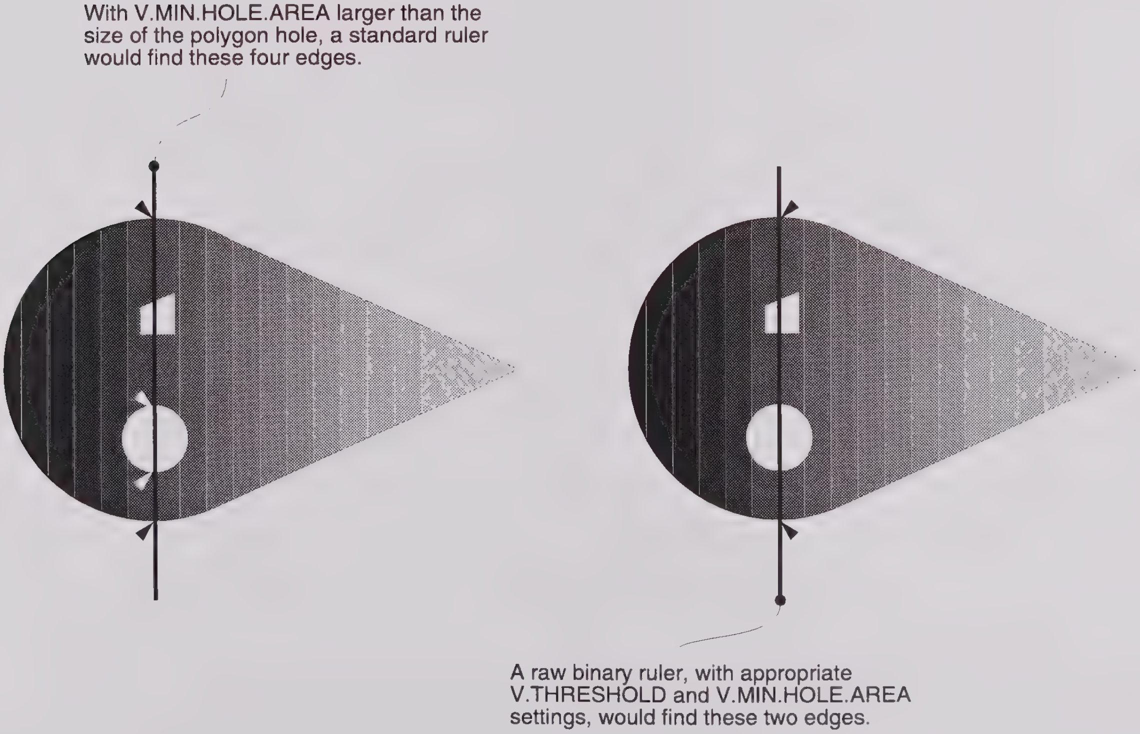

With V.MIN.HOLE.AREA larger than the size of the polygon hole, a standard ruler would find these four edges.
A raw binary ruler, with appropriate V.THRESHOLD and V.MIN.HOLE.AREA settings, would find these two edges.

Figure 10-8. Ruler Types

Ruler Speed and Accuracy

The absolute speed and accuracy of rulers will depend on your particular application. In general:

- Ruler length and the number of transitions affect speed.
- Raw binary rulers are the fastest.
- Linear rulers are faster and more accurate than arc rulers.
- Linear rulers are faster and more accurate when they are nearly vertical or horizontal to the vision coordinate system.
- Fine edge rulers are the most accurate.

Finder Tools

The finder tools allow you to locate lines, points, and arcs within the field of view. The finder tools operate on raw grayscale data. This allows you to look for edges in an unprocessed image. In some cases the finder tools will tell you all you want to know about an image; in other cases you will perform further processing based on what you discovered with the finder tool.

In all the finder tools you will specify an area-of-interest within which to search for the line, point, or arc.

The behavior of all three finder tools is similar, so we will describe only the line finder, VFIND.LINE, in detail. The syntax for the other finder tools is described in the *AdeptVision Reference Guide*. The simplified syntax for VFIND.LINE is:

```
VFIND.LINE (cam.virt) data[] = ibr
```

`cam.virt`	is replaced with a virtual camera number (the V.EDGE.STRENGTH parameter from this camera will be used by the line finder). The default value is 1.
`data`	is replaced with a variable name for the data array into which you want the results of the search placed. (The values placed in the array are described in “VFIND.LINE Array” below.)
`ibr`	is replaced with an image buffer region specifying a rectangular AOI (shape 1 is the most common shape).

Figure 10-9 shows a sample VFIND.LINE area-of-interest.

VFIND.LINE Array

The array values returned to the VFIND.LINE data array are:

data[0]	TRUE if a line was fit, FALSE otherwise.
data[1]	TRUE if any part of the search window fell off the screen.
data[2]	X coordinate of a point on the line nearest to the search starting point.
data[3]	Y coordinate of a point on the line nearest to the search starting point.
data[4]	Angle of the fit line relative to the vision X axis (horizon).
data[5]	Percentage of the line's extent for which edge points were found.
data[6]	Maximum distance between the fit line and the most distant edge point used to compute the found line. The value is in pixels.

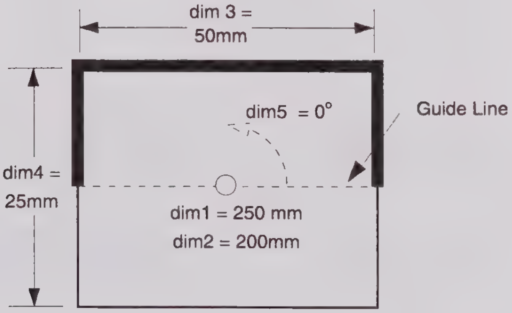


Figure 10-9. Line Finder Search Area

Line Finder Tool Polarity

An important point to remember when using the line finder tool is that it locates dark-to-light transitions as viewed from the "dark side" of the tool. In Figure 10-9, the dark side is the side with the heavy line. When a finder tool is displayed in the vision window, the dark side is the dark blue half of the tool search area. In order for the tool to find a line, a transition from dark to light must occur within the window as viewed from the dark blue side of the tool. If only light-to-dark transitions occur (as viewed from the dark blue side of the tool), a line will not be found. Figure 10-10 illustrates the polarity of a finder tool. In Example A, a dark-to-light transition occurs within the window, and the lower edge of the rectangle is found. In Example B, no dark-to-light transition takes place so an edge is not found (the light-to-dark edge is ignored). In order to find an edge with the tool in this position, the angle would have to be made 180° so the dark side of the tool would be in the rectangle. In Example C, the first dark-to-light transition is found, and the remaining transitions are ignored (the tool quits processing as soon as an edge is detected). In Example D, the first edge is a light-to-dark transition, so it is ignored and the second edge (a dark-to-light transition) is found.

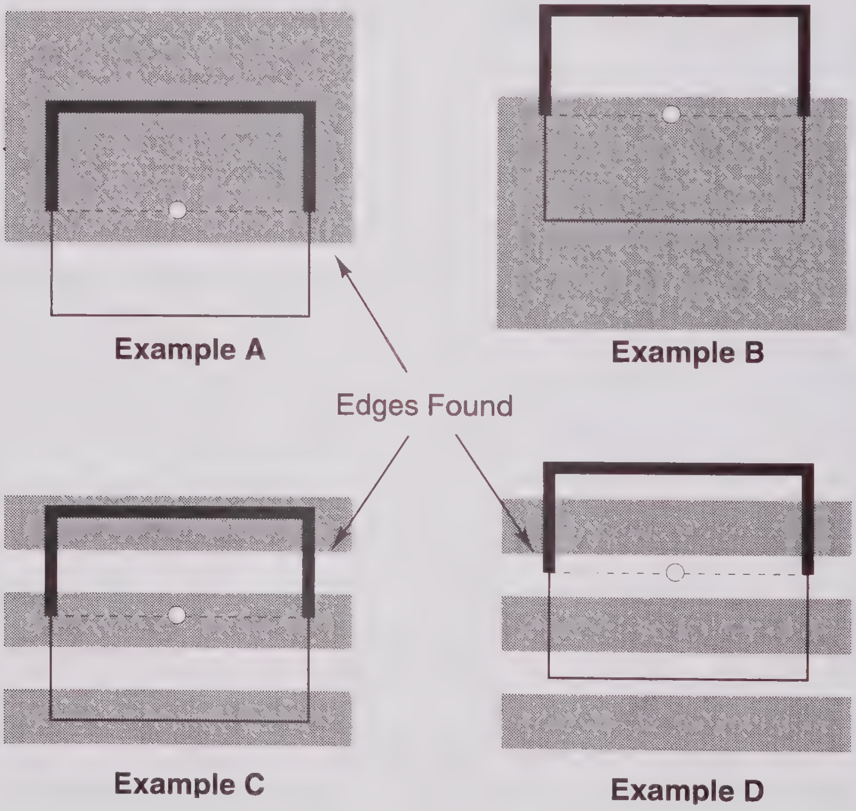


Figure 10-10. Finder Tool Polarity

VFIND.LINE Example

This example locates the two straight edges of the sample object. Using the location and angle information returned in the data arrays from each finder tool and the V$^+$ trig functions, the intersection of the straight edges can be calculated with high accuracy. This type of strategy is particularly useful on an object similar to our sample object, where the intensity changes at the intersection point are low enough that the system will have trouble recognizing exactly where the point is.

```
; Select a live grayscale image with a graphics overlay

  VDISPLAY -1, 1

; Acquire and process an image with camera 1

  VPICTURE (1)

; Place two line finders

  VDEF.AOI 2000 = 1, 80, 80, 30, 10, -205
  VDEF.AOI 3000 = 1, 80, 50, 30, 10, 25
  VFIND.LINE (1) data1[] = 2000
  VFIND.LINE (1) data2[] = 3000

; Pass the line finder data to a routine that calculates a line-to-line
;  intersection (a sample routine is shown in the description of VFIND.LINE
;  in the "AdeptVision Reference Guide" and a similar routine is shown in the
;  programming example in Chapter 8).

  x1 = data1[2]
  y1 = data1[3]
  ang1 = data1[4]
  x2 = data2[2]
  y2 = data2[3]
  ang2 = data2[4]

  IF data1[0] AND data2[0] THEN
      CALL line_line(x1, y1, ang1, x2, y2, ang2, x, y)
      TYPE "The lines intersect at x = ", x, " and y = ", y, "."
  ELSE
      TYPE "One of the line finders failed."
  END
```

Figure 10-11 shows the tool placement for the preceding example.

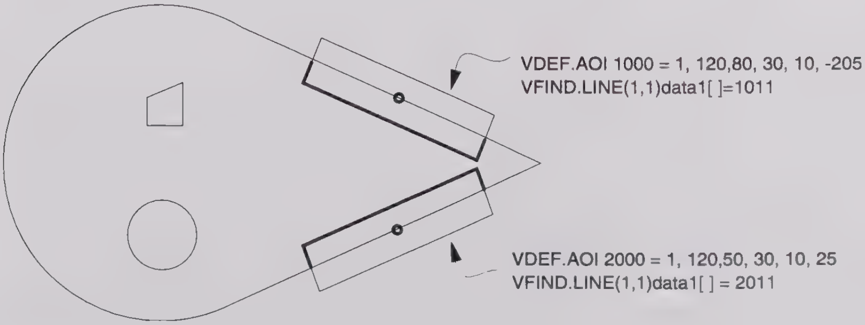

VDEF.AOI 1000 = 1, 120,80, 30, 10, -205
VFIND.LINE(1,1)data1[ ]=1011
VDEF.AOI 2000 = 1, 120,50, 30, 10, 25
VFIND.LINE(1,1)data1[ ] = 2011

Figure 10-11. Line Finder Example

Processing Windows (VWINDOW)

In many cases, only a small section of the field of view will be of interest to you. You can reduce processing time by using the VWINDOW instruction to process only sections of the field of view that have critical features.

More than one processing window can be placed on an image, and windows can overlap. Using multiple windows allows you to inspect different image areas using different combinations of switches and parameters.

Once you have placed a window, you can use VLOCATE, VFEATURE, and other vision tools just as you would if you were working with a fully processed field of view. The difference is that the results of these instructions will take into account only the portion of the image inside the window.

To use a processing window, you first acquire an unprocessed image by executing a VPICTURE instruction in mode 2 (quick frame grab). You then issue a VWINDOW instruction to process the area you are interested in.

After a VWINDOW instruction, boundary analysis is performed on the area inside the window. VLOCATE and VFEATURE can now be used to obtain data about the regions within the area of interest window. Vision tools that operate on processed image data can also be used.

The simplified syntax for a rectangular processing window is:

`VWINDOW` `(cam.virt)` **`ibr`**

`cam.virt`	is replaced with a virtual camera whose switch and parameter settings will be used during processing by the window tool.
`ibr`	is replaced with the an image buffer region specifying a rectangular AOI. Shapes 1 and 4 are the normal shapes for a processing window.

VWINDOW Example

For this inspection we'll use the point found by the two VFIND.LINE instructions in our previous example (Figure 10-11). Using this point (x,y) we'll place an area-of-interest window that just encompasses the sample object.

```
w.width = 90
w.height = 60
VDEF.AOI 5000 = 1, x-w.width/2, y, w.width, w.height

VWINDOW (cam.virt) 5011
```

The above instruction results in the window illustrated in Figure 10-12. (In this case, for maximum speed in locating the x,y position, you would use type #–1 line finders.)

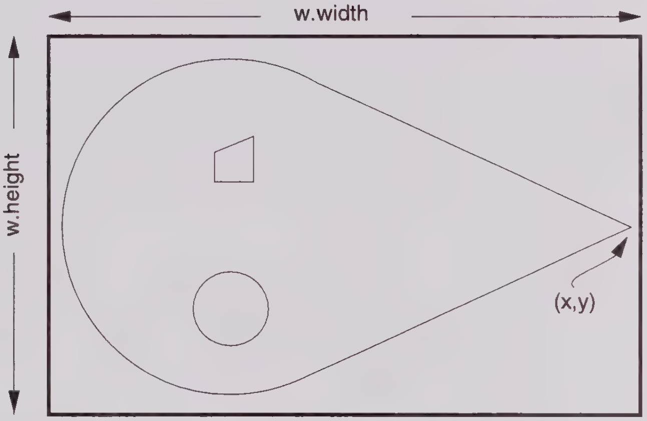


Figure 10-12. VWINDOW Example

Vision Tools: Inspection Windows (VWINDOWI)

VWINDOWI returns graylevel or binary data about the portion of an image inside the inspection window. The number of nonzero pixels, average graylevel, standard deviation of the graylevels, object and background pixel counts, and number of edge points in the window are calculated with this instruction.

VWINDOWB returns basic information about the binary image. See the *AdeptVision Reference Guide* for details on these instructions.

Vision Tool Data Arrays

All vision tools return data to the array you specify in the instruction line. A potential problem arises with these arrays when your application is cycling through multiple inspections and placing the data in the same array during each iteration of the cycle. The entire array is not overwritten during each cycle. Only the currently generated values are overwritten.

For example, suppose you were inspecting parts with linear rulers and you expected to find six edges in each part. If a defective part containing only four edges was inspected, the fifth and sixth array cells would still hold the distance to the fifth and sixth edges left over from the previous inspection. To detect this problem, check the array element that indicates how many edges were detected before processing the ruler.

Windows, Windows, Windows

Documentation for AdeptVision VXL uses the term "windows" in several contexts, which can lead to confusion. These are the different windows AdeptVision VXL uses:

Window used by itself refers to the windows that are open on the display screen. These are the windows you can open and close, perform operations in, and view the results of vision operations in.

An **inspection window** results from issuing a VWINDOWI instruction. The information available from this type of window is what is returned in the data array specified when the instruction was issued.

A **processing window** is the window resulting from issuing a VWINDOW or VWINDOWB instruction. A VWINDOW instruction makes VFEATURE details available. Vision models can be processed within this type of window, and rulers can be placed inside these windows. A VWINDOW instruction by itself returns no data. A VWINDOWB instruction makes basic binary image data available through a specified array.

Vision Model Processing

11

Introduction . . . 169
    Why Use Prototype Recognition? . . . 169
    Why Use Correlation? . . . 170
    Why Use OCR? . . . 170
Training Prototypes . . . 170
    Creating Prototypes . . . 171
    Editing Prototypes . . . 172
    Preview Window . . . 175
    Zoom Buttons . . . 175
    Message Window . . . 175
    Edit Buttons . . . 175
    Editing Operation Data Box . . . 176
    Edge/Region Data Boxes . . . 176
    Edge/Region Radio Buttons . . . 176
    Prototype Training Hints . . . 177
    SubPrototypes . . . 177
    Prototype Parameters . . . 177
    Setting Prototype Parameters . . . 177
        Verify percent . . . 178
        Effort level . . . 178
        Min/max area . . . 178
        Limit position . . . 178
        Edge weights . . . 178
        Assign cameras . . . 178
Using Prototypes . . . 179
    Recognizing a Prototype . . . 179
    Prototype-Relative Inspection . . . 180
    Prototype-Relative Part Acquisition . . . 180
Performing Correlation Matches . . . 181
    Creating a Correlation Template . . . 181
    Matching a Correlation Template . . . 181

Performing Optical Character Recognition 183
    Training an OCR Font 183
    Font Planning 184
    Character Recognition 185
        OCR Examples 186
Prototype Model Switches and Parameters 187
Loading and Storing Vision Models 189
    VSTORE 189
    VLOAD 190
    Displaying Vision Models 191
    Deleting Vision Models 191
    Renaming Vision Models 192

Introduction

Vision model processing has two major steps, training and recognition.

The first step, training, involves creating an idealized "vision model" of the object you want to recognize. After this model has been created, it can be stored in a disk file and called into vision memory when needed.

The second step, recognition, involves placing the vision models in memory, presenting actual objects to the camera, and instructing the vision system to see if any of those objects match the models stored in vision memory.

AdeptVision VXL has three types of vision model processing: prototypes, optical character recognition (OCR), and correlation.

Why Use Prototype Recognition?

The most common use for prototype recognition is identifying objects that enter the field of view in a random fashion. A typical application would be a manufacturing operation where several different objects are produced and then placed in random order and orientation on a conveyor for inspection or acquisition by a robot. You would use prototype recognition to identify each object and then take appropriate action based on which object was identified. Prototyping is also the only way to separate objects that touch or overlap and thus form a single region. It is also the only way to recognize multiple disjoint regions that comprise a single object. Some things to remember when using prototypes are:

- Prototype recognition is processing-intensive
  If you have only a few simple objects, you might be able to recognize them more efficiently with other vision tools.
- All vision tools can be applied to recognized objects
- VFEATURE data is available for recognized objects
- Prototype recognition enables you to recognize objects that are touching or slightly overlapping or are formed from disjoint regions
- A trained prototype will have its own frame of reference
  This can be used either to place other inspection tools or as part of the vision transformation for guided vision (see Chapter 13).

Why Use Correlation?

Correlation is similar to prototyping, but the training and recognition process is simpler. In correlation, a "template" is created from a region of pixels in a processed image. This template is then compared to a section of the field of view to see if the pixel pattern is repeated in that section. Correlation is used when you want to know how well objects in the field of view match a template of an ideal part. Correlation is "normalized" so that additive or multiplicative changes in lighting do not affect the correlation results. Unlike prototype matching, correlation matches must have the same orientation as the template.

Why Use OCR?

Optical character recognition has two primary uses: text recognition and text verification. Text recognition identifies characters from a trained font. Text verification verifies that a string of expected characters was in fact found in the field of view (verifying date and lot codes, for example).

Training Prototypes

Prototype training is the process of creating prototype models of objects that you want the system to be able to recognize. During prototype training you will:

- Present multiple instances of an object to the system for training
  The system will average the data from these instances to create the vision model that it will use for recognition.
- Name the prototype and specify the following parameters that will be used during prototype recognition:
  - The effort level the system should apply when attempting recognition
  - The percent of the object boundary that must agree with the prototype before recognition will be considered successful
  - Constraints on the object's position and orientation that must be met for successful recognition

Creating Prototypes

To create a prototype:

1. Set the switches and parameters to the settings that provide the best possible image. Data provided by boundary analysis will be used to create the prototype model.
2. Make sure the correct calibration data is loaded for the cameras you will be using.

   CAUTION: Changing camera settings or calibration after you train a prototype will invalidate the prototype.

3. Select:

   Models ➔ Train prototype

   If no other prototypes are in vision memory, you will be prompted for a prototype name. If other prototypes are loaded, you will be given the option to train additional instances of loaded prototypes or to create a new prototype.

4. If the "Select the prototype..." pop-up window is presented, click on "<new prototype>".
5. In the "Type new name" pop-up window, enter a prototype name (using normal V^{+} variable naming conventions), and click on **Ok**. (This name is for an individual prototype, not the disk file for storing the prototypes. Multiple prototypes can be stored in a single file. See "VSTORE" on page 189.)
6. A screen listing the 32 virtual cameras will be presented. Click on the numbers of the virtual cameras you want to be able to recognize this prototype (the cameras must be calibrated). Click on **Done** when you have finished selecting virtual cameras. Cameras can be added or deleted during subsequent training sessions.
7. Place the object you want to train in the field of view and click on the **Ok** button in the training window.
8. Edit the prototype. (Editing is detailed in the next section.)
9. When you have completed editing of the prototype example, select:

   Done ➔ Use example

10. The training window will display the default verify percentage (75%). Click on the percentage to change it. Click on Ok to accept the percentage displayed in the dialog box.[1]
11. The training window will display the available effort levels. The suggested effort level will be highlighted. Click on Ok to accept the suggested effort level.
12. Select:

    New example ➔ New Example

    and follow steps 5 through 7 to train at least five additional examples of the prototype. Orient the part differently during each training session. After training each additional example, the program will prompt you to:

    a. Select a corner in the new example.

    b. Select the corresponding corner in the existing prototype. Click on Done when you have selected the two corners.

    c. The system will attempt to fit the new example to the existing prototype. If the match is successful, a blue outline will be overlaid on the existing prototype. If the outline and the prototype match, click on Yes. If the match is unsuccessful, you will have to select different features (or additional features) to match, or abandon the example.
13. When you have finished training examples, select:

    Done ➔ Done
14. The prototype model now exists only in vision memory. It must be stored to disk so it can be retrieved for future use. Activate the monitor window and store the prototype using the VSTORE command.

Editing Prototypes

If you are not in the prototype training window, select:

Models ➔ Train prototype

and click on the prototype you want to edit. Select:

New example ➔ New example

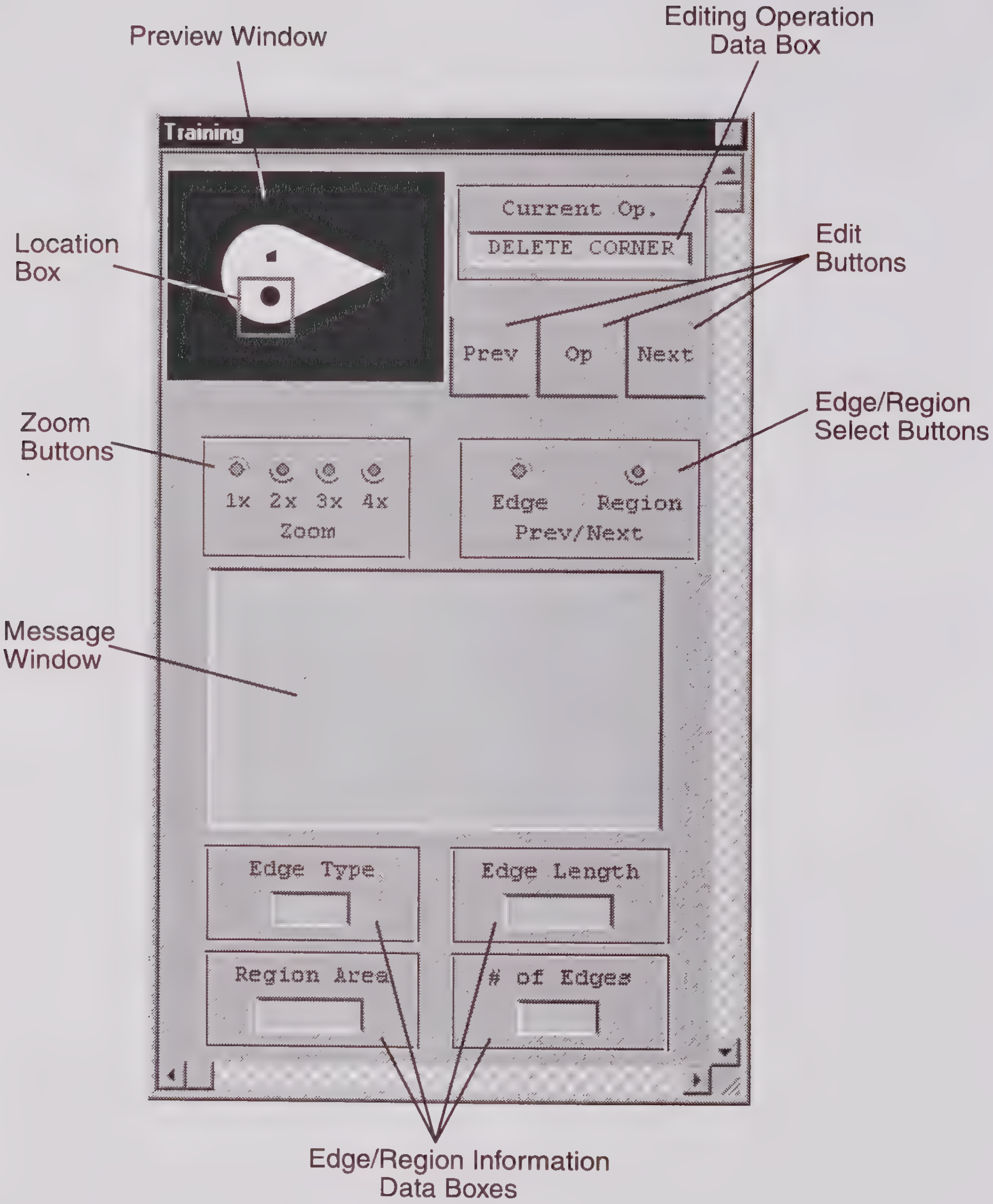
---

[1] Verify percent and effort level are prototype parameters that will have meaning only when you begin using prototypes. These two prototype parameters, along with the other prototype and system parameters, are discussed later in this chapter.

Place an example of the prototype in the field of view and click on the **Ok** button in the training window. A graphic representation of the prototype example will be presented, showing arcs in purple, lines in yellow, and corners as white dots. During prototype editing, you will edit the boundaries fit by the system so they match your object as closely and simply as possible. The most common editing tasks you will perform are:

- Removing extra corners
- Turning arcs into lines
- Deleting features that are unimportant or are part of the background

Figure 11-1 shows the prototype training window and its functional groups of features. The process of editing a prototype using the training window is described in the following sections.



Current Op.

DELETE CORNER

Preview Window
Editing Operation Data Box
Training
Location Box
Edit Buttons
Prev
Op
Next
Zoom Buttons
1x
2x
3x
4x
Zoom
Edge/Region Select Buttons
Edge
Region
Prev/Next
Message Window
Edge Type
Edge Length
Region Area
# of Edges
Edge/Region Information Data Boxes

Figure 11-1. Prototype Editing Operations

Preview Window

This window shows a reduced view of the vision window. When ● **1x** is selected, the preview window and the vision window show the same extent of view. When ● **2x** (or greater) is selected, the objects in the vision window will be magnified, and a location box will appear in the preview window showing the area of the vision window you are working on. You can move to a different area of the vision window by clicking on this location box and dragging it to a new area.

Zoom Buttons

These buttons allow you to work with different levels of magnification of the prototype object. The area you have zoomed to is shown in the Preview Box.

Message Window

This box will display information and error messages during the prototype training process.

Edit Buttons

There are two methods of editing a prototype: clicking on the object's features with the pointing device and using the Edit Buttons. The main difference between the two methods is that data reported in the Edge/Region Information Windows is available only when using the Edit Buttons. The editing operation that will be performed (using either method) is selected from the **Operation** menu in the vision window. The current operation is shown in the Editing Operation data box.

When you edit with the pointing device, the current operation will be performed on the line, arc, or corner nearest the pointer click.

When you edit with the Edit Buttons:

> The first time you click on **Prev** or **Next** , an "X" will appear on one of the lines or arcs of the prototype. If you click on **Op**, the operation indicated by the Editing Operation Window will be performed.
>
> If the Edge button is selected, the next time you click on **Prev** or **Next** , the "X" will move to the previous or next line or arc in the region. Clicking on **Op** will perform the current operation.
>
> If the Region button is selected, the next time you click on **Prev** or **Next** , the "X" will move to the previous or next region in the vision window. Clicking on **Op** will perform the current operation.

Editing Operation Data Box

This data box shows the editing operation that will be performed using the Edit Buttons, or by clicking on the prototype. The edit operation is selected from the **Operation** menu in the prototype window. The editing tasks are:

Delete corner	Delete the corner nearest to a mouse click, or the next corner in sequence when **Op** is clicked.
Restore corner	Restore a corner deleted with a delete corner operation.
Arc <=> Line	Convert a line to an arc, or an arc to a line.
Delete region	Delete the region nearest to the mouse click, or the region currently selected with the Edit Buttons. (Can be performed only on the first prototype example.)
Delete edge	Delete the edge currently selected with the Edit Buttons or the edge nearest the mouse click. (Can be performed only on the first prototype example.)
Create corner	Place a corner at the mouse click or, when **Op** is clicked, on the currently selected line or arc. (Can be performed only on the first prototype example.)

Edge/Region Data Boxes

When you are editing using the Edit Buttons, these data boxes show:

- Edge type (line or arc)
- Region area in pixels
- Edge length (distance in pixels from one corner to the next)
- Number of edges in the region (holes are not included in this count)

This data will not be displayed if you are using the mouse to edit the prototype.

Edge/Region Radio Buttons

These buttons work in conjunction with the Edit Buttons. When ● **Edge** is selected, pressing **Prev** or **Next** will select the previous or next edge in a region.

When ● **Region** is selected, pressing **Prev** or **Next** will select the previous or next region within the field of view.

Prototype Training Hints

After you have completed prototype training, you can still train additional examples of a part or change the prototype parameters (described later in this chapter). If you make any changes to an existing prototype, you must *store the changes* using the VSTORE command (if you use the same file name, the existing disk file must be renamed or deleted).

When you train the first example, make the prototype as simple as possible. When you train additional examples, do as little editing as possible.

SubPrototypes

A region within a prototype can be designated as a subprototype. Subprototypes allow you to more accurately determine the position and "goodness of fit" of a prototype based on the region selected as a subprototype. See the description of VDEF.SUBPROTO in the *AdeptVision Reference Guide.*

Prototype Parameters

In addition to the parameters described above, each prototype has several prototype parameters associated with it. System parameters are associated with a virtual camera and will be in effect for any prototype recognized by that virtual camera. Prototype parameters are associated with a trained prototype and will be in effect for that given prototype, regardless of the virtual camera that acquired the image.

Setting Prototype Parameters

To change parameters for a given prototype (prototype parameters are described below):

1. Load the prototype into vision memory using the VLOAD command.
2. Activate the vision window and select:

   Models ➔ Train prototype

3. Select the prototype model from the displayed list.
4. Select the parameter you wish to set from the **Params** menu. A dialog box will be displayed that will allow you to change the parameter value. Repeat for as many parameters as you want to change.
5. After you have made all changes, select the monitor window and store the prototype to disk using the VSTORE command.

Verify percent

This parameter sets the percentage of total boundary length (including holes) that must be common to both the prototype model and the current region before recognition will be successful. This parameter can be used in conjunction with the system parameter V.MAX.VER.DIST to control:

- Objects incorrectly recognized as matching a prototype
- Objects matching a prototype that are not recognized

Effort level

Effort level affects recognition accuracy and processing speed. Recognizing prototypes with few distinguishing features as well as recognizing prototypes among multiple overlapping objects will require higher effort levels and more processing time.

Min/max area

Changing the minimum area setting allows you to ignore noncritical features of an object.

Changing the maximum area setting allows you to isolate an area within a large object, or ignore large, noncritical areas within the field of view.

Limit position

These parameters allow you to constrain the location and rotation variance an object can have from the prototype model and still be recognized.

Edge weights

In some cases, accuracy of prototype recognition can be improved by weighting an object's edges. Important features of an object can be given a high weight; unimportant features can be given a low weight. Edge weights work in conjunction with verify percent to determine how closely an object must match the prototype model for successful recognition.

Assign cameras

Any cameras you will be using to attempt recognition of a given prototype must be assigned to that prototype.

Using Prototypes

In the previous section we learned how to create prototype objects. This section will show you how to use those prototypes.

Recognizing a Prototype

In order for the system to recognize a prototype, the following steps need to be taken:

1. The prototype must be loaded into vision memory (using the VLOAD command).
2. The camera calibration that was in effect when the prototype was trained must be loaded.
3. The system switches V.BOUNDARIES and V.RECOGNITION must be enabled.

After an image containing prototype objects has been acquired, the individual prototypes can be removed from the vision queue using the VLOCATE instruction. The syntax for VLOCATEing a prototype is:

```
VLOCATE (cam.virt, 2) "proto_name", proto_loc
```

`cam.virt`	is the virtual camera whose queue holds objects recognized as matching the specified prototype. Default = 1.
2	indicates that a particular object is to be removed from the vision queue.
`proto_name`	is the prototype you are looking for (must have been loaded to vision memory).
`proto_loc`	receives a transformation that defines the object's location in the field of view.

Once an object has been recognized and removed from the queue you will be able to retrieve all the VFEATURE data available for blobs (unrecognized regions), as well as data available only from recognized prototypes. See Appendix B for additional VFEATURE data.

In some cases, recognizing an object will be the only inspection you need to make. In other cases, you may want to use rulers and other vision tools to make a more thorough inspection of the object. Chapter 14 describes the use of prototype-relative inspections. This inspection strategy allows you to place vision tools on the prototype regardless of its location and orientation in the field of view.

Prototype-Relative Inspection

You can use DEF.TRANS, VFEATURE(2), VFEATURE(3), and VFEATURE(7) to establish a reference frame for all vision tools.

Prototype-Relative Part Acquisition

If the objects you are acquiring:

- Are similar and cannot be identified by blob recognition or by using a combination of finder and ruler tools
- Do not have a strong elliptical character or other features that define the object's rotation
- Are touching or overlapping or are formed by disjoint regions

then prototyping may be the best way to define a reference frame for the objects.

Prototypes have their own reference frame based on the orientation of the part the first time it was trained. When a prototype is recognized (VLOCATE operation), a reference frame based on the recognized object is returned. The following code will move to a recognized prototype (assuming the robot is a four-axis SCARA—see Chapter 13 for more information on guided vision operations):

```
     cam.virt = 1
     ENABLE V.RECOGNITION [cam.virt];enable prototype recognition

; Acquire a processed image and locate the prototype.

     VPICTURE (cam.virt) -1
     VLOCATE (cam.virt, 2)"sample_object", proto.loc

; Use the prototype object location to acquire the recognized prototype

     HERE #cur.loc
     DECOMPOSE jt[1] = #cur.loc
     SET link2 = HERE:INVERSE(TOOL):RZ(-jt[3]):TRANS(,,jt[4])
     SET obj.loc = link2:to.cam:proto.loc:grip.trans
     MOVE obj.loc
```

Performing Correlation Matches

A correlation template is simply an array of graylevel values recorded from the pixels in a specified area of the field of view. When a correlation match is attempted, this array of graylevel values is compared with the graylevel values in a given search area. The template and the search area can be any size as long as the search area is larger than the template. Larger templates and search areas will increase processing time for a template match.

Since changes in ambient lighting will alter the graylevel values recorded, template correlation is "normalized" to account for changes in lighting from when the template was created to when a correlation match is attempted. Lighting changes that uniformly affect the field of view will not affect template matching.

Creating a Correlation Template

A correlation template is created with the program instruction:

```
VTRAIN.MODEL (cam.virt) $tmpl_nn, , ibr
```

`cam.virt`	is the virtual camera to use.
`$tmpl_nn`	is the name of the correlation template. Correlation template names begin with "tmpl_" and end with a number between 1 and 50. Multiple templates can be stored in a single disk file.
`ibr`	is a defined image buffer region (see **"Defining a Tool Area-of-Interest (AOI)" on page 146**).

Once a correlation template has been created, it can be stored, loaded, and compared with new camera images. The VCORRELATE program instruction searches for a template match in an image. See description of VCORRELATE in the *AdeptVision Reference Guide* for details on hierarchical and binary correlation. These options speed up correlation searches.

Matching a Correlation Template

An area of the field of view is compared to a defined correlation template with the program instruction:

```
VCORRELATE (cam.virt) data[] = tmp.num, ibr
```

`cam.virt`	is the number of the virtual camera to use.

`data[]`	is an array name to receive the results of the correlation operation:
data[0]	receives the correlation value of the best match found (1 is perfect correlation).
data[1]	receives the x value of the area matching the template.
data[2]	receives the y value of the area matching the template.
`tmp.num`	is the number of a loaded correlation template.
`ibr`	is a defined image buffer region (see **"Defining a Tool Area-of-Interest (AOI)" on page 146**).

Performing Optical Character Recognition

This section describes the optical character recognition capacities (OCR) of AdeptVision VXL.

Training an OCR Font

Before characters can be recognized or verified, a sample of the font containing all characters that might be encountered must be trained. As with all vision model processes, before models can be built or recognized, the camera must be installed, adjusted, and calibrated. The system parameters should be set to acquire the best image possible.

Before a font can be trained it must be defined with the program instruction:

```
VDEF.FONT (op) font.num, $chars, height, black?
```

op	determines what action the instruction will initiate:
0	define a new or replace an existing font (default)
1	modify an existing font
font.num	number of the font to be defined (or altered).
$chars	list of characters in the font.
height	typical height of the largest character (must be between 6 and 63 pixels).
black?	boolean indicating whether the font is dark characters on a light background or light characters on a dark background. The default is TRUE (dark characters on a light background).

Fonts are trained with the program instruction:

```
VTRAIN.MODEL (cam.virt) $font, $font.chars, ibr
```

cam.virt	virtual camera whose switches and parameters will be used when training the font.
$font	a defined font in the form "font_nn".
$font.chars	the characters in the font sample, entered in the order in which they occur in the sample.

`ibr`	a defined image buffer region (see **"Defining a Tool Area-of-Interest (AOI)" on page 146**).

Train the font 5 - 15 times, using samples that represent the range of examples the system might encounter.

> **NOTE:** Fonts are trained based on the binary image. Therefore, a constant, optimized image must be used during training and recognition to obtain accurate, consistent OCR results.

Font Planning

After fonts have been defined and trained, but before sample characters can be recognized, the vision system must plan a recognition strategy. Planning will take place the first time recognition is attempted on an unplanned font or when planning is specifically requested. Since font planning can take a few minutes, we recommend you plan fonts before using them in an application. The instruction to plan a font is:

```
VTRAIN.MODEL(cam.virt, 1) $font
```

As fonts are planned, each character planned is shown in the upper left corner of the vision window. When planning is complete, a matrix showing the font characters vs. the found characters is displayed. A red square at the intersection of a font character and a sample character indicates a well defined and trained character.

After a font is trained, a matrix is displayed that shows the relative similarities among the characters in the font. The rows of the matrix are marked with the characters in the font as are the columns. The color of the intersecting cell indicates how similar the character in the row is to the character in the column. Red indicates very high similarity, and the corner-to-corner diagonal cells should be red. Orange and yellow indicate strong similarity and indicate one character may get interpreted as the other. Greens indicate a moderate similarity—characters such as E and F or O and Q may regularly show this similarity. As long as lighting remains consistent and the characters are clearly printed, these characters will be correctly identified. Gray indicates little similarity—these characters are unlikely to be confused with each other. **Figure 11-2** shows a sample matrix. All the characters show very high similarity with themselves. The F and E show a strong similarity that may cause confusion. The M and N show a moderate similarity which should not be confusing as long as conditions remain consistent.

If characters show an unacceptable similarity:

- Train additional instances of the font

- Improve the lighting conditions
- Optimize the image
- Train a new sample of the font

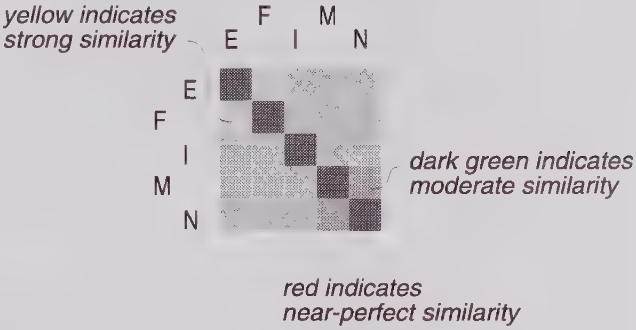

yellow indicates strong similarity
E
F
I
M
N
E
F
I
M
N
dark green indicates moderate similarity
red indicates near-perfect similarity

Figure 11-2. Font Similarity Matrix

Character Recognition

The VOCR instruction performs font recognition or verification. The syntax is:

```
VOCR (cam.virt, op) data[], = font_num, $expected, ibr
```

`cam.virt`	virtual camera number (default is 1)
`op`	0 = text verification (default) 3 = text recognition
`data[]`	text verification or recognition data. For `op` = 0: data[0] = number of character regions found and analyzed data[1] = average score of "`$expected`" characters verified data[2] = minimum score of "`$expected`" characters verified

For `op` = 3:

data[0] = number of character regions found and analyzed
data[1] = average score of two most likely values per region
data[2] = minimum score of two most likely values per region
data[3] & data[4] not used
data[5] = ASCII value of character most likely to match region
data[6] = score of most likely character
data[7] = ASCII value of character 2nd most likely to match region

	data[8] = score of 2nd most likely character data[9] - data[12] repeats data[5] - data[8] for the second analyzed region region, data[13] - data[16] for the third analyzed region, etc.
font_num	number of a trained and loaded font
`$expected`	expected text for `op` = 0
ibr	number of a defined image buffer region (see **"Defining a Tool Area-of-Interest (AOI)" on page 146**)

OCR Examples

The following code will output the characters found in the area defined by cx, cy, dx, and dy (font 1 must be trained and loaded).

```
      VPICTURE (cam.virt)
      VWAIT
      VDEF.AOI 3000 = 1, cx, dx, cy, dy
      VOCR (cam.virt,3) data[],= 1, 3000

;The first array value is the number of characters found

      found = data[0]

;The ASCII values of the found characters are stored in every fourth array cell
;starting at 5

      index.inc = 4

;Output the characters

      FOR x = 5 TO (found*index.inc)+4 STEP index.inc
        type $CHR(data[x]), " ", /S
      END
      TYPE
```

The following code will output the average verification score of characters from the string $ver.string found in the area defined by cx, cy, dx, and dy:

```
      VPICTURE (cam.virt)
      VWAIT
      VOCR(cam.virt,0) data[],= 1, $ver.string, 3000
      TYPE "The average verification score is: ", data[1]
```

The VOCR instruction has several different options and returns extensive data on recognition and verification processes. See the description of VOCR in the *AdeptVision Reference Guide.*

Prototype Model Switches and Parameters

The following tables list the switches and parameters that affect the prototype model process.

Table 11-1. Prototype Model Switches

Switch	Default	Effects
V.RECOGNITION	✓	Disabling this switch will cause the system to behave as if no prototypes have been defined. Must be enabled to perform prototype recognition. (Not required for OCR or correlation.)
V.DISJOINT		A single object may appear to the vision system to be two separate objects (e.g., a dark object with a white line down the middle would look like two objects). If you are attempting prototype recognition on this type of object, this switch will have to be enabled or the object will not be recognized. Disable this switch when you are not doing prototype analysis. When doing region analysis, this switch must be disabled for hole data to be gathered.
V.TOUCHING		If the objects you are attempting to recognize are touching each other, the system will see them as one object and fail to recognize multiple touching objects. If you need to recognize touching objects, enable this switch. This switch increases processing time for object recognition. See the *AdeptVision Reference Guide* for details on how V.TOUCHING, V.DISJOINT, and V.OVERLAPPING interact.
V.OVERLAPPING		Enabling V.OVERLAPPING will improve recognition of objects that are overlapping. This switch increases processing time for object recognition and should be disabled if objects do not overlap. (V.TOUCHING is assumed to be enabled whenever this switch is enabled.)
V.SHOW.BOUNDS		If this switch is enabled, the vision system will display the results of attempting to fit lines and arcs during prototype recognition. This switch is useful during development because it allows you to see what the vision processor is going through during object recognition. V.RECOGNITION must be enabled.
V.SHOW.RECOG	✓	If this switch is enabled and an object is recognized, the silhouette of the recognized prototype will be overlaid on the object. The "SHOW" switches are time consuming and are generally turned off in the production environment.

Table 11-1. Prototype Model Switches (Continued)

Switch	Default	Effects
V.SHOW.VERIFY		Enabling this switch will cause the system to display all attempts the system makes during prototype recognition. This switch is useful during development when you attempt to create prototypes that produce the most accurate results in the least amount of time. It should be disabled during normal operations.

Table 11-2. Prototype Model Parameters

Parameter	Default	Range	Effects
V.BORDER.DIST	0	0 100	Allows you to disable prototype recognition processing on objects that are not entirely within the field of view.
V.MAX.TIME	5	1 999	Sets the maximum time the vision system will spend trying to recognize a prototype.
V.MAX.VER.DIST	3	1 16	Sets the pixel variance allowed for successful fitting of image boundaries to the prototype model.
V.LAST.VER.DIST	0	0 16	Sets the pixel variance allowed for successful fitting of image boundaries to the prototype model when a successfully recognized prototype is reverified. When this switch is set to 0, the additional verification process is defeated.

Loading and Storing Vision Models

The vision processor board has its own memory that is separate from system processor memory. Trained vision models reside in this memory area. VSTORE stores a vision model (or group of similar models) to a disk file. VLOAD loads a vision model or group of models (stored with the VSTORE command) from a disk file to vision memory.

> **NOTE:** Vision models already in RAM cannot be overwritten by new models with the same name. You must first use the VDELETE or VRENAME command to delete or rename the existing model. See "Deleting Vision Models" on page 191 and "Renaming Vision Models" on page 192 for details.

VSTORE

VSTORE works the same way as STORE except it will store vision models from the vision processor memory to a disk file.[1] Additionally, VSTORE supports the ObjectFinder tool.

> **NOTE:** The type of model being supported is determined by the name, which has been trained as either a prototype or an ObjectFinder model. The name is first checked against the lists of prototypes for backward compatibility. Therefore, you should not use the same name for a prototype model and an ObjectFinder model.

The syntax for VSTORE is:

```
VSTORE drive: file_spec = model_1,...,model_n
```

To store prototypes "goodpart", "badpart", and "okpart" to the file PARTSCMP.PTS on the B: drive, enter the command:

```
VSTORE B:partscmp.pts = badpart, goodpart, okpart
```

To store correlation templates "tmpl_1" and "tmpl_2" to the file TPLATES.VS on the default drive, enter the command:

```
VSTORE tplates = tmpl_1, tmpl_2
```

All correlation template names must have the form "tmpl_nn".

To store font "font_3" to the file FONTS.VS on the A: drive, enter the command:

---

[1] VSTORE is also a program instruction.

```
VSTORE fonts = font_3
```

All font names must have the form "font_nn".

Only one type of vision model can be stored in a file. The instruction:

```
VSTORE models = a.proto, font_4, tmpl_5
```

will result in an error.

Remember that after training, vision models reside only in vision memory. They must be explicitly stored to a disk file or they will be lost when the controller is turned off.

> **NOTE:** When no model names are specified, VSTORE stores *all* the models in memory to the disk file. There is no way to globally store only the ObjectFinder models or only the prototype models. If you want to store only one type of model to the disk file, you must store each model individually by specifying the model name.

If the file specification does not contain a file extension, the default extension ".VS" is added when storing vision models.

VLOAD

In order to use vision models, you must load them to vision memory (rather than the system memory). VLOAD loads files from a disk file to vision memory; its syntax is similar to LOAD.[1]

> **NOTE:** This command supports the ObjectFinder tool. Except where noted, the usage is the same as for prototypes.

The syntax for VLOAD is:

`VLOAD` `drive:` **`file_spec`**

To load the disk file of vision models "VMODELS.VS" from the C: drive into vision system processor memory, issue the command:

```
VLOAD C:vmodels
```

".VS" is automatically added if an extension is not specified.

---

[1] VLOAD is also a program instruction.

> **NOTE:** The type of model being supported is determined by the name, which has been trained as either a prototype or an ObjectFinder model. The name is first checked against the lists of prototypes for backward compatibility. Therefore, you should not use the same name for a prototype model and an ObjectFinder model.

Displaying Vision Models

Vision models in vision memory can be displayed and listed from the **Models** menu. To display a graphic representation of a vision model:

1. Select **Show prototype**, **Show font**, or **Show template** from the **Models** menu.
2. A pop-up window will appear showing the names of all the selected vision models currently in vision memory. Click on the model you want to see, and the model will be displayed in the vision window. (Vision models must be loaded with the VLOAD command before they can be displayed.)

To see an alphabetic listing of all the prototypes currently in vision memory, select **List prototypes**, **List fonts**, or **List templates** from the **Models** menu. A dialog box will appear listing all appropriate models in vision memory.

Deleting Vision Models

To delete a model from vision memory:

1. Select **Delete prototype**, **Delete font**, or **Delete template** from the **Models** menu.
2. Click on the model to be deleted from vision memory.
3. The system will prompt you to verify the deletion. Click on **Yes** to delete the prototype. Click on **No** to abandon the operation.

The command/instruction:

```
VDELETE model_name
```

will also delete models from vision memory. See the *AdeptVision Reference Guide* for more details.

> **NOTE:** This command supports the ObjectFinder tool. Except where noted, the usage is the same as for prototypes.

This operation removes a model from vision memory, not from the disk file in which it is stored. To permanently delete a vision model, the disk file must be deleted with the FDELETE command.

> **NOTE:** The type of model being supported is determined by the name, which has been trained as either a prototype or an ObjectFinder model. The name is first checked against the lists of prototypes for backward compatibility. Therefore, you should not use the same name for a prototype model and an ObjectFinder model.

Renaming Vision Models

To rename a vision model:

1. Select **Rename prototypes**, **Rename fonts**, or **Rename templates** from the **Models** menu.
2. A list of appropriate models in vision memory will be presented. Click on the model to be renamed.
3. Type the new name in the dialog box presented. Click on **Ok** to change the name. Click on **Prev** to abandon the change.

The monitor command:

```
VRENAME new_name = old_name
```

will also rename a vision model. See the *AdeptVision Reference Guide* for more details.

> **NOTE:** This command supports the ObjectFinder tool. Except where noted, the usage is the same as for prototypes.

Renaming a model in vision memory does not change the name in the disk file the model is stored in. To permanently change a vision model's name, the disk file must be deleted with the FDELETE command and the models (if any) must be stored with the VSTORE instruction.

> **NOTE:** The type of model being supported is determined by the name, which has been trained as either a prototype or an ObjectFinder model. The name is first checked against the lists of prototypes for backward compatibility. Therefore, you should not use the same name for a prototype model and an ObjectFinder model.

Programming AdeptVision VXL

12

Introduction 194

Application Development Strategy 194

Vision Inspection Example Program 195

Developing the Program Code 198

- Program Header and Variables Declarations 198
  - Set the Camera Environment 199
  - Acquire an Image and Start Processing 200
  - Locate the Object and Begin Inspections 201
  - Output the Results 208
- Further Programming Considerations 210

The Complete Inspection Vision Program 211

- The Main Program - inspect.part 211
- Subroutine - line.line 218
- Subroutine - init.program 220
- Subroutine - write.vwin 221

Introduction

This chapter details the development of an AdeptVision VXL program. The program includes vision instructions that were presented in the last two chapters as well as other V^+ program instructions. As you go through this example, remember that we are not attempting to present the most efficient vision inspection application. We are attempting to present examples of vision instructions in a simple, straightforward context.

This chapter assumes that you are familiar with basic V^+ programming. All the commands presented in this example are detailed in the V^+ *Language Reference Guide* or the *AdeptVision Reference Guide*.

This chapter develops a basic inspection application. Chapter 13 develops a robot guidance vision application.

Application Development Strategy

We recommend that vision inspection applications be developed in the following sequence:

1. Install the controller and any other equipment you will be using to deliver or remove parts.
2. Select a lighting strategy and install the lighting equipment (see **Appendix E**). Make the lighting environment as consistent as possible.
3. Determine the lens requirements (see **Appendix D**). Install the cameras and lenses.
4. Optimize the camera image (select a live grayscale image):

   Focus the lens.

   Set the f-stop (aperture) for maximum contrast.

   Set V.THRESHOLD (select a live binary image). The command VAUTOTHR will provide suggested threshold levels.
5. Calibrate the cameras (see **"Camera Calibration" on page 55**).
6. Determine the part location strategy. If parts will always be in the same location, inspection tools can be placed relative to the vision coordinate system. If the parts will be presented to the camera in varying locations, inspection tools will have to be placed using a "part-relative" strategy. The

program in this chapter uses finder tools and boundary analysis data to determine tool locations. Additional part-relative strategies are discussed in **Chapter 14**.

7. Determine which vision tools to use to make inspections.
8. Write the application code.
9. Debug the application.
10. Fine-tune the application.

Vision Inspection Example Program

The program detailed in this chapter will inspect the sample object that we have worked with in the last several chapters. Below is a list of the major steps that the program will perform (see the flow chart in **Figure 12-1**).

1. A digital output signal will be sent to a conveyor belt. The belt will bring the object into the field of view. When the object is in place, a digital input signal will be sent to the system indicating the part is ready. When the part is in place, the digital output signal to the belt will be turned off.
2. The first step after the part is in place will be to take a picture.
3. When the objects are placed on the conveyor belt, the tail will be facing forward. An object's location and rotation can vary, but must be within limits set by the placement of two line finders we will use to locate the object. If the object is positioned outside the allowed area, it will be sent back. If it is located, its centroid and rotation will be determined.
4. Based on the object's location and orientation, we will process the image area that just encompasses the object.
5. We will now make five inspections:
    a. Check that the center of the circular and polygon-shaped holes are correctly spaced from the object center (within ±0.5mm).
    b. Check the diameter of the circular hole. It should be 10mm (±1mm).
    c. Check the angle of the slanted side of the polygon. It should be 25° (±2°).
    d. Check the arc on the top of the object. Its center should be centered between the polygon and circular holes.
    e. The surface of the object should have a constant gradation from the front to the back. If this gradation exceeds a certain value, the part will be rejected.

6. If any inspection fails, a program will be called to remove the bad part and the conveyor will bring in a new part and begin again. If the object passes all inspections, the conveyor will move a new part into position and carry the inspected part out of the field of view.

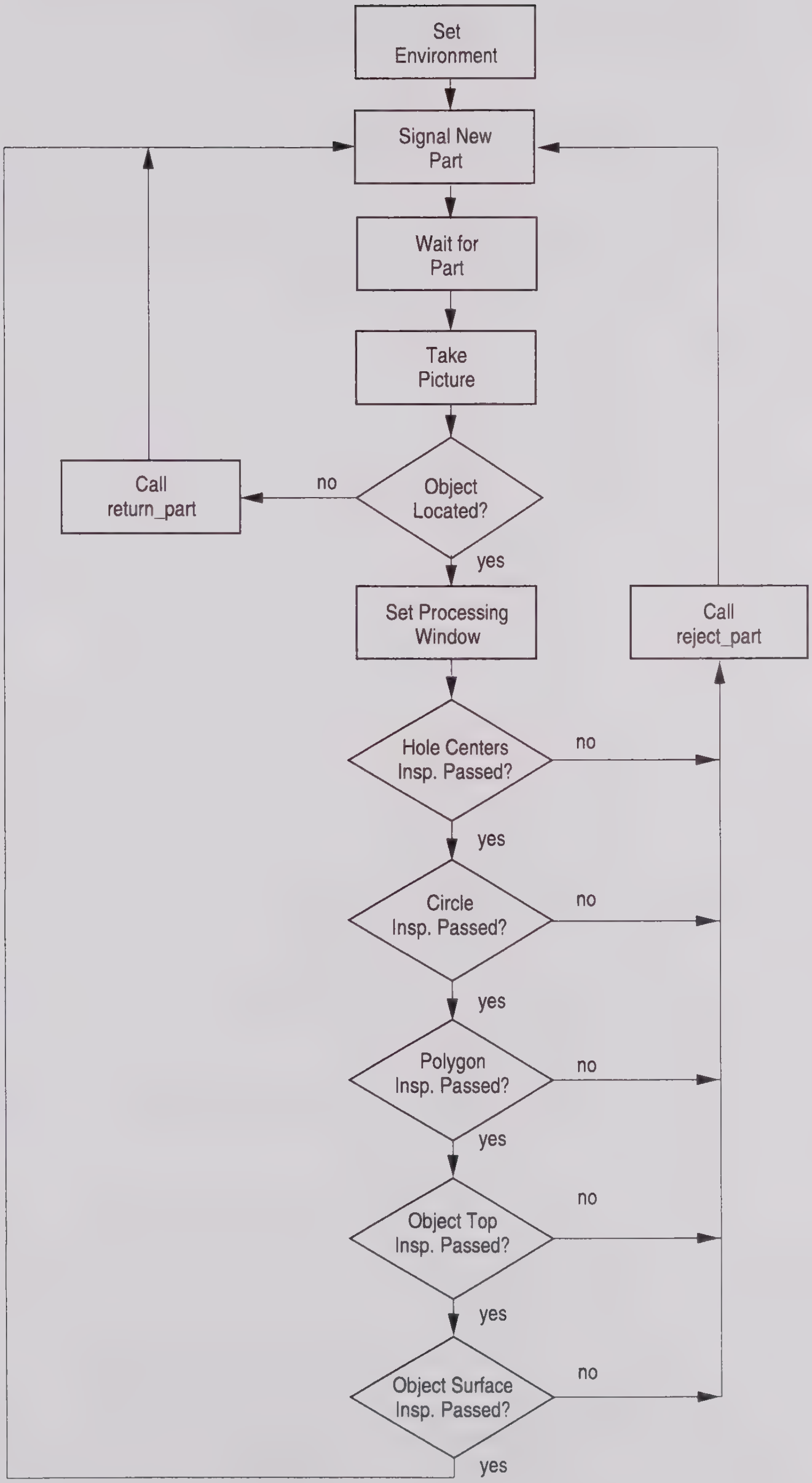

Set Environment
Signal New Part
Wait for Part
Take Picture
Object Located?
no
Call return_part
yes
Set Processing Window
Call reject_part
Hole Centers Insp. Passed?
no
yes
Circle Insp. Passed?
no
yes
Polygon Insp. Passed?
no
yes
Object Top Insp. Passed?
no
yes
Object Surface Insp. Passed?
no
yes

Figure 12-1. Application Flow Chart

Developing the Program Code

Program Header and Variables Declarations

All programs should begin with a header that gives the program abstract, creation date, side effects, input and output parameters, and any modifications that have been made. The header should be similar to this:

```
.PROGRAM inspect.part(re_init)

;
; ABSTRACT:  Inspect the sample object for defects in the round and
;       polygon shaped holes, the arc at the front of the object, and the
;       surface gradation.
;
; INPUT PARM:   re_init     determine whether to call the system initialization
;                           routine. 1 = reinitialize, 0 = no initialization
;
; OUTPUT PARM: None
;
; SIDE EFFECTS: The global variables 'num_parts' and 'avg_time'
;       will be updated.
;
```

The next section of your program should contain the variable declarations. The V+ language allows you to declare variables dynamically, but these variables will be global to all programs. To guarantee you do not inadvertently use the same variable name used globally by another program, you should declare all variables used exclusively within your program to be automatic variables.

```
; Declare local variables
;

    AUTO obj_width                    ;object width
    AUTO cent_circlex, cent_circley   ;x, y center of circular object
    AUTO obj_centx, obj_centy         ;x, y center of the object
    AUTO arc_centx, arc_centy         ;x, y center of object arc
    AUTO gvalue                       ;acceptable graylevel variance
    AUTO grulerx, grulery             ;starting point of g-level ruler
    AUTO good_part                    ;boolean indicating status of part
    AUTO di.part_ready                ;digital sig indicating part is ready
    AUTO cycle_time                   ;average inspection cycle time
    AUTO do.belt                      ;digital sig for conveyor belt
    AUTO poly_angle, circ_diam        ;correct part dimensions
    AUTO poly_dist, poly_act          ;          "
```

```
     AUTO rnd_dist, rnd_act                ;                 "
     AUTO win_ibr, rul_ibr, lfdr_ibr       ;define image buffer regions
     AUTO afdr_ibr, grul_ibr
     AUTO last, $msg[19], $err
     AUTO i, lun

; Initialize known values

     obj_length = 0
     obj_centx = 85                        ;object center X (within 12mm)
     obj_centy = 60                        ;object center Y (within 12mm)
     obj_width = 82                        ;object width
     obj_hgt = 50                          ;object height
     gvalue = 10                           ;acceptable graylevel variance
     poly_angle = 25                       ;correct angle of polygon edge
     poly_dist = 19                        ;correct dist from object center
     rnd_dist = 17                         ;              "
     do.belt = 31                          ;digital signal for conveyor belt
     di.part_ready = 1032                  ;digital signal for part ready
     good_part = TRUE                      ;assume the part is good
     circ_diam = 10                        ;correct diameter of circular hole
     cam = 1                               ;virtual camera used for inspections
```

Set the Camera Environment

An important principle to remember when programming AdeptVision VXL is that when any program makes changes to the switches and parameters associated with a given camera, those changes are in effect for any further pictures taken by that camera regardless of the program using the camera. This means that all critical switches and parameters should be explicitly set at the beginning of each program. Otherwise, changes made by other programs running during the same session as your program may unexpectedly change critical switch/parameter settings, and cause your program to behave erratically.

Disabling switches that aren't needed for your program will improve processing time by reducing the amount of data the system has to gather about each image.

```
; Set switches and parameters

     ENABLE V.HOLES[cam]                   ;hole information is needed
     ENABLE V.BINARY[cam]                  ;processing to be in binary mode
     ENABLE V.BOUNDARIES[cam]              ;region analysis will be done
     ENABLE V.BACKLIGHT[cam]               ;dark objects on a light background
     DISABLE V.PERIMETER[cam]              ;data not needed
     DISABLE V.DISJOINT[cam]               ;must be disabled to get hole data
     DISABLE V.RECOGNITION[cam]            ;no prototype recognition
     DISABLE V.TOUCHING[cam]               ;we have only one part
     DISABLE V.OVERLAPPING[cam]            ;
     DISABLE V.2ND.MOMENTS[cam]            ;data not needed
     DISABLE V.STROBE[cam]                 ;strobes are not being used
```

```
      DISABLE V.MIN.MAX.RADII[cam]        ;data not needed
      PARAMETER V.MIN.AREA[cam] = 101     ;filter small areas
      PARAMETER V.MIN.HOLE.AREA[cam] = 100  ;          "
```

When we execute the main program, we send in an indication of whether to reinitialize the camera and cycle time variables. CALL the initialization program if the boolean is true (this routine is on page 220).

```
; If necessary, initialize the cycle time variables and load camera calibration

      IF re_init THEN
          CALL init.program(cam)
      END

; Set the display mode to a graphics mode so we can see the processed image

      VDISPLAY (cam) 3
```

Acquire an Image and Start Processing

We are now ready to start the application, and as with so many things in life, the first thing we do is wait. In this case we are waiting for the object to come into position in the field of view. Digital output signal 31 controls conveyor belt movement. Digital input signal 1032 has been configured to sense when the object is in position. As soon as signal 1032 is detected, signal 31 should be turned off, the system should begin timing the inspection operations, and the program should resume execution. (See the *Adept MV Controller User's Guide* for details on installing digital I/O.)

```
; Start conveyor belt

      SIGNAL do.belt

; Wait for part ready signal (sig 1032) before beginning processing

      WAIT SIG(di.part_ready)
      SIGNAL -do.belt                     ;shut off conveyor belt
      TIMER 1 = 0                         ;start timing operation
```

After the part-in-place signal has been received, we are ready to take a picture. Since we will be reducing the processed area, we want to acquire an unprocessed image.

```
; Acquire an unprocessed image with camera 1

     VPICTURE (cam) 2
```

Locate the Object and Begin Inspections

We now have an unprocessed image and are ready to check the location of the object. The program "line.line( )" makes this inspection. This program returns the coordinates of the object tail, the object rotation, and a boolean indicating the object was found. See "Subroutine - line.line" on page 218 for details.

```
; Locate sample object, calculate the tail point and object's rotation

     CALL line.line(tailx, taily, obj.rot, good_part)
```

The subroutine "return_part" takes the required steps when a part is rejected. Since the reject routine could have many options, it is left as a dummy call for you to complete.

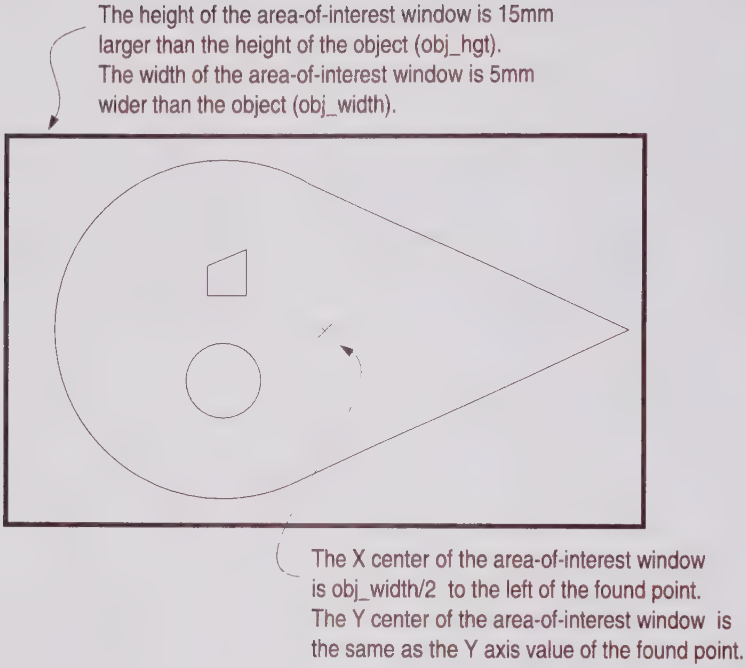
```
; Call return program and get next part if point is not found

     IF NOT good_part THEN
         TYPE "The object was not found or was incorrectly positioned."
         CALL return_part()
     END ; if
```

We now know that the part is in place. We also know the location of the object tail and the rotation of the object. We will use this data plus the dimensions of the object to set an area-of-interest window. The VWINDOW instruction will define the image area to be processed and then process that area (see Figure 12-2).

```
;Use the coordinates of the object tail to set a processing window

     IF good_part THEN
         win_ibr = 3000                  ;AOI 3
        VDEF.AOI win_ibr = 1, tailx-obj_width/2, taily, obj_width+5,
                                                           obj_hgt+15, obj.rot
        VWINDOW (cam) win_ibr
```


The height of the area-of-interest window is 15mm larger than the height of the object (obj_hgt). The width of the area-of-interest window is 5mm wider than the object (obj_width).

The X center of the area-of-interest window is obj_width/2 to the left of the found point. The Y center of the area-of-interest window is the same as the Y axis value of the found point.

Figure 12-2. Executing the VWINDOW Instruction

We now have an object in the vision queue, and we are ready to do inspections on that object.

The first thing we will do is VLOCATE the object and check to be sure it has two holes. If it does not, we reject the part. If the part is to be rejected, we call the program "reject_part", which will activate the necessary machinery to remove the part and signal the conveyor belt to bring in the next part.

```
; Remove the object from the vision queue and make its characteristics
; available to the VFEATURE function.

    VLOCATE (cam, 2) "?", obj.loc

; Check to see if a part was successfully located.

        IF NOT VFEATURE(1) THEN
           TYPE "A hole was not located."
           CALL reject_part()
           good_part = FALSE
        END
    END ; if good_part

; Check that there are two holes in the part
```

```
     IF good_part THEN
         IF VFEATURE(17) <> 2 THEN
            TYPE "The part has an incorrect number of holes."
            CALL reject_part()
            good_part = FALSE
         END
     END ; if good_part
```

The next inspection involves checking the distance from the centers of the circular and polygon holes to the center of the object. The part will be rejected if these values differ by more than 0.5 millimeters from their ideal values.

```
; Remove the holes from the queue and check their centroids.
; Remove the largest hole (the circle) from the queue.

     IF good_part THEN
         VLOCATE (cam, 4, 1) , rnd.loc

; Save the circle's centroid X and Y values

         cent_circlex = VFEATURE(2)
         cent_circley = VFEATURE(3)

; The next hole removed will be the polygon

         VLOCATE (cam, 4) , poly.loc

; Calculate the distance

         rnd_act = DISTANCE(obj.loc,rnd.loc)
         poly_act = DISTANCE(obj.loc,poly.loc)

; Compare the distances and reject part if they are not within .5mm of correct.

         IF ABS(rnd_act-rnd_dist) > 0.5 THEN
            TYPE "The round hole is out of alignment."
            CALL reject_part()
            good_part = FALSE
         END; if ABS

         IF ABS(poly_act-poly_dist) > 0.5 THEN
            TYPE "The polygon hole is out of alignment."
            CALL reject_part()
            good_part = FALSE
         END; if ABS

     END ; if good_part
```

If the part passes this inspection, we turn to the circular hole to see if its diameter agrees with the correct value to within 1mm. We will use a linear ruler to perform this inspection.

```
; Place a ruler that starts at the center of the circular hole and
; goes past its edge.

    IF good_part THEN
        rul_ibr = 4000;AOI 4
        VDEF.AOI rul_ibr = 2, cent_circlex, cent_circley, 10, 0
        VRULERI (cam, 0, 1) circ_hole[] = rul_ibr

; Check the value of the first transition (which will be the radius)
; against the required value.

         IF circ_hole[0] == 0 THEN
            TYPE "The radius of the circular hole could not be determined."
         ELSE
            IF ABS((2*circ_hole[2])-circ_diam) > 1 THEN
                TYPE "The circular hole is not the correct size."
                CALL reject_part()
                good_part = FALSE
            END ; if ABS
         END    ; if circ_hole[0]
    END ; if good_part
```

We are now ready to inspect the polygon to see if the angle of the slanted face equals 25° (±2°). We will use a VFIND.LINE tool to make this inspection. The center coordinates of the polygon are still available through VFEATURE so we can center a VFIND.LINE tool on these coordinates.

```
; Place a VFIND.LINE tool at the center of the polygon, and have it
; look in the negative Y direction for an edge. Search from dark
; to light (object to background).

    IF good_part THEN
        lfdr_ibr = 501100;AOI 5
        VDEF.AOI lfdr_ibr = 1, VFEATURE(2), VFEATURE(3), 10, 10, obj.rot
        VFIND.LINE (cam, 0) poly_hole[] = lfdr_ibr

; Compare the actual value with the acceptable value
```

```
        IF ABS(poly_hole[4]-poly_angle) > 2 THEN
            TYPE "The poly shaped hole is incorrectly oriented."
            CALL reject_part()
            good_part = FALSE
        END; if ABS
    END ; if good_part
```

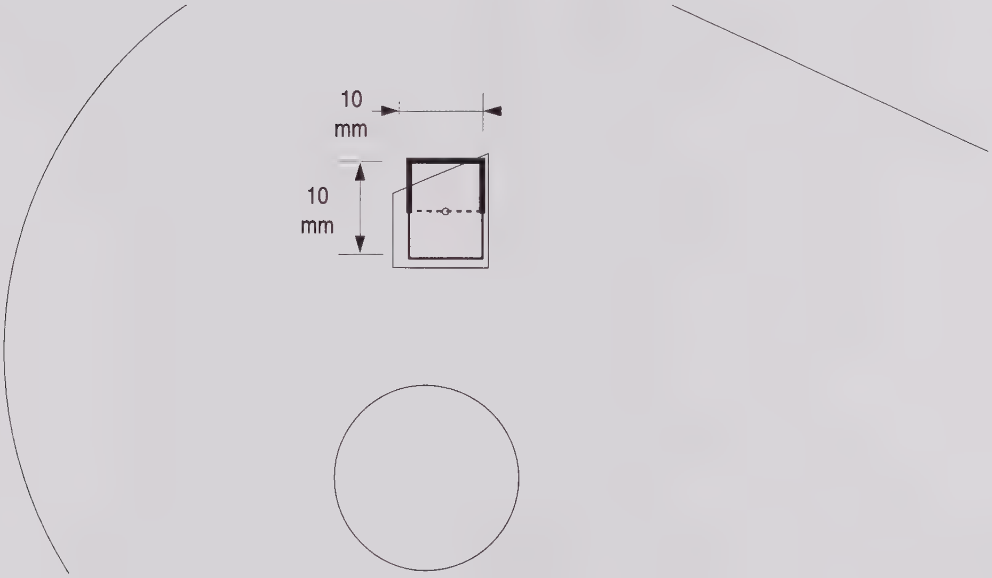


Figure 12-3. Executing a VFIND.LINE Instruction

The time has come to inspect the location of the arc on the front of the object with respect to the center line of the two holes. We will use the X,Y values of the object center to place the arc finder. If the actual center of the object arc does not coincide with the midpoint between the two holes (±1mm), the part will be rejected. We will use the VFIND.ARC tool to see if the arc center is centered between the two holes in the object.

```
    IF good_part THEN

; Calculate the X,Y center point for the arc finder

        x = DX(obj.loc)
        y = DY(obj.loc)

;Use the locations of the two holes to calculate the midpoint

        arc.centx = (DX(rnd.loc)+DX(poly.loc))/2
        arc.centy = (DY(rnd.loc)+DY(poly.loc))/2
```

```
; Place an arc finder centered around the two holes and look from
; dark to light for an arc.

        afdr_ibr = 6000;AOI 6
        VDEF.AOI afdr_ibr = 5, x, y, obj_hgt/2, obj_hgt/2+5, 90+obj.rot,
                                                              270+obj.rot
        VFIND.ARC (cam) arc_data[] = afdr_ibr

; Check to see if an arc was found

        IF NOT arc_data[0] THEN
           TYPE "The outer radius was not located."
           CALL reject_part()
           good_part = FALSE
        END; if not
     END ; if good_part

; Calculate the center variance

     IF good_part THEN
        IF ((ABS(arc_data[2]-arc_centx) > 100) OR (ABS(arc_data[3]-arc_centy)
                                                              > 1)) THEN
           TYPE "The outer radius is not correctly aligned with the two
                                                                holes."
           CALL reject_part()
           good_part = FALSE
        END; if ABS
     END ; if good_part
```

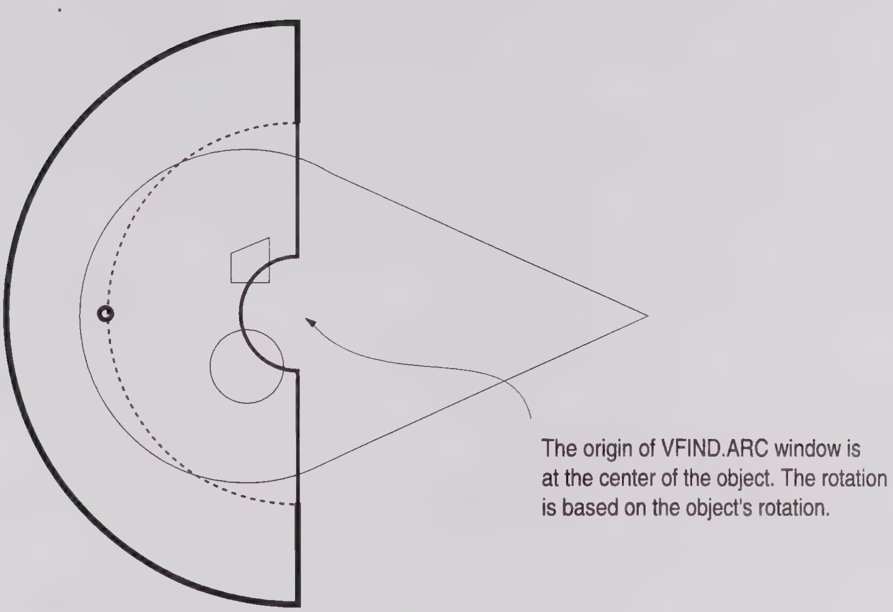

The origin of VFIND.ARC window is
at the center of the object. The rotation
is based on the object's rotation.

Figure 12-4. Executing a VFIND.ARC Instruction

We have at last come to the final inspection: looking at the surface gradation of the part to see that there is a constant gradation from light to dark across the part. We will use a grayscale ruler to perform this operation. A graylevel ruler differs from a regular ruler in that it returns the graylevel intensities for each pixel along the ruler rather than the transitions found along the ruler.

From the data array returned by the previous VFIND.ARC instruction, we know the center and radius of the object arc. We also know the width of the object. With this information we can place a ruler along the X axis and make sure it stays within the object.

```
; Place a graylevel ruler along the width of the object, starting at
; object tail and ending 5mm from the edge of the object.

     IF good_part THEN
         grul_ibr = 7000;AOI 7
         VDEF.AOI grul_ibr = 1, tailx-5, taily, obj_width-10, 180+obj.rot
         VRULERI (1, 1) gray_data[] = grul_ibr

; Calculate the graylevel changes every 25 pixels and compare them
; with the acceptable value (gvalue).
```

```
    FOR i = 2 TO (gray_data[0]-25) STEP 25
        good_part = ABS(gray_data[i]-gray_data[i+25]/gvalue) > 0.9
        good_part = good_part AND (ABS((gray_data[i]-gray_data[i+25])
                                                          /gvalue < 1.1))
        IF NOT good_part THEN
            CALL reject_part()
            TYPE "Graylevel ruler failed."
            GOTO 90;exit on failure
        END
    END    ; for i = 2
END ;if good_part
```

Output the Results

If the part has gotten to this stage, it has passed all its inspections and is ready to be moved on down the line. We now read the cycle timer to see how long the cycle took and update the global variables that keep track of cycle time. Then we ship the part to the next station.

```
; Read the timer

    90 cycle_time = TIMER(1)

; Calculate the total time.

     total_time = cycle_time+(avg_time*num_parts)
     IF good_part THEN
         num_parts = num_parts+1
     END
     IF num_parts == 0 THEN
         avg_time = 0
     ELSE
         avg_time = total_time/num_parts
     END
```

Once we have gathered the data, we will output this information as text to the vision window. V$^+$ provides several "G" commands to control output to graphics windows. The GTYPE instruction is used in the subroutine write.vwin( ) to do this. The subroutine write.vwin( ) is introduced in the next code segment, and the code for the complete subroutine is shown at the end of this chapter. The other "G" commands are covered in the *V$^+$ Language Reference Guide*.

```
; Output the data to the vision window.

     $msg[0] = "Average Processing Time: "
     $msg[1] = $ENCODE(avg_time)
     $msg[2] = "Number of units passed: "
     $msg[3] = $ENCODE(num_parts)

; Get the mm/pixel ratio and divide the screen into 20 lines

     VGETCAL (cam) cal[]
     hgt = cal[16]*480                    ;Screen height in millimeters
     inc = hgt/20

; Start at the first line and indent text one line

     x = inc
     y = inc

     FOR i = 3 TO 0 STEP -1

; Write text results to vision window

         CALL write.vwin(cam, x, y, $msg[i], $err)
         y = y+inc
         IF $err <> "" THEN
             TYPE $err                    ;Output error message
             EXIT
         END
     END
```

Before we look at the next object, let's set V.THRESHOLD if it hasn't been set recently. We'll use timer 2 to decide when to change thresholds. In this case we will reset the threshold every half hour (1,800 seconds).

```
; Read timer 2 to see how long it has been since the threshold was set.
; If it exceeds 30 minutes, set V.THRESHOLD and restart timer 2.

     ttime = TIMER(2)
     IF ttime > 1800 THEN
         VWAIT                            ;make sure the processor is idle
         VAUTOTHR tarray[]
         IF tarray[0] THEN
             PARAMETER V.THRESHOLD = tarray[1]
         END; if
         TIMER 2 = 0
     END ; if

.END
```

One program cycle is now complete. The number of cycles executed can be controlled several ways. A WHILE loop around the entire program could watch for operator input of a digital input signal. A FOR loop with an operator input index could control an absolute number of cycles. Or, as is the case in this program, the program is executed with a –1 argument indicating the program should loop until it is aborted.

Further Programming Considerations

The program presented here is not very robust and could be modified to make it much more "crash-proof". For example, inspections can be done to eliminate the requirement that the part enter the field of view within 12mm of the desired location. In Chapter 14 we will describe the use of frames and prototype-relative processing that will allow you to inspect objects in any orientation.

The data arrays that are returned by the finder and ruler tools provide information with which to make much more rigid inspections of the part. You will also find that the assumptions made about a particular feature being in the expected place may not be warranted. Whenever a VLOCATE is done, check VFEATURE(1) to see if the locate was successful.

Also bear in mind that during each successive cycle, only the array values generated during the current cycle will overwrite the values generated during the last cycle. So if you expect four transitions from a ruler, and only three are generated, the array location that would normally hold the fourth value will not be blank but will hold the fourth value from the previous cycle.

This program provides no opportunity for operator intervention when errors are generated. You will want your programs to be much more fault-tolerant. The simplest method is to place an IF...THEN clause around conditions that indicate errors and prompt for operator attention. In a more complicated vein, the program could communicate with other cell devices or computers in an attempt to nonfatally resolve errors.

As you build a more robust program, you will likely find that each inspection should be broken down into its own subroutine. This will make the program more readable and maintainable.

The Complete Inspection Vision Program

The Main Program - inspect.part

```
.PROGRAM inspect.part(re_init)
;
; ABSTRACT:  Inspect the sample object for defects in the round and
;       polygon shaped holes, the arc at the front of the object, and the
;      surface gradation.
;
; INPUT PARM:   re_init    determine whether to call the system initialization
;              routine. 1 = reinitialize, 0 = no initialization
;
; OUTPUT PARM: None
;
; SIDE EFFECTS: The global variables 'num_parts' and 'avg_time'
;       will be updated.
;
; Declare local variables
;

     AUTO obj_width ;object width
     AUTO cent_circlex, cent_circley;x, y center of circular object
     AUTO obj_centx, obj_centy;x, y center of the object
     AUTO arc_centx, arc_centy;x, y center of object arc
     AUTO gvalue;acceptable graylevel variance
     AUTO good_part;boolean indicating status of part
     AUTO di.part_ready;digital sig indicating part is ready
     AUTO cycle_time;average inspection cycle time
     AUTO do.belt;digital sig for conveyor belt
     AUTO poly_angle, circ_diam;correct part dimensions
     AUTO poly_dist, poly_act;                "
     AUTO rnd_dist, rnd_act;                "
     AUTO win_ibr, rul_ibr, lfdr_ibr;define areas-of-interest
     AUTO afdr_ibr, grul_ibr
     AUTO last, $msg[19], $err
     AUTO i, lun

; Initialize known values

     obj_length = 0
     obj_centx = 85;object center X (within 12mm)
     obj_centy = 60;object center Y (within 12mm)
     obj_width = 82;object width
     obj_hgt = 50;object height
     gvalue = 10;acceptable graylevel variance
     poly_angle = 25;correct angle of polygon edge
     poly_dist = 19;correct dist from object center
     rnd_dist = 17;            "
     do.belt = 31;digital signal for conveyor belt
     di.part_ready = 1032;digital signal for part ready
     good_part = TRUE;assume the part is good
     circ_diam = 10;correct diameter of circular hole
     cam = 1 ;virtual camera used for inspections

; Set switches and parameters

     ENABLE V.HOLES[cam];hole information is needed
     ENABLE V.BINARY[cam];processing to be in binary mode
     ENABLE V.BOUNDARIES[cam];region analysis will be done
     ENABLE V.BACKLIGHT[cam];dark objects on a light background
     DISABLE V.PERIMETER[cam];data not needed
     DISABLE V.DISJOINT[cam];must be disabled to get hole data
     DISABLE V.RECOGNITION[cam];no prototype recognition
     DISABLE V.TOUCHING[cam];we have only one part
     DISABLE V.OVERLAPPING[cam];
     DISABLE V.2ND.MOMENTS[cam];data not needed
     DISABLE V.STROBE[cam];strobes are not being used
     DISABLE V.MIN.MAX.RADII[cam];data not needed
     PARAMETER V.MIN.AREA[cam] = 101  ;filter small areas
     PARAMETER V.MIN.HOLE.AREA[cam] = 100  ;          "

; If necessary, initialize the cycle time variables and load camera calibration

     IF re_init THEN
        CALL init.program(cam)
     END

; Set the display mode to a graphics mode so we can see the processed image.

     VDISPLAY (cam) 3

; Start conveyor belt

     SIGNAL do.belt

; Wait for part ready signal (sig 1032) before beginning processing

     WAIT SIG(di.part_ready)
     SIGNAL -do.belt;shut off conveyor belt
     TIMER 1 = 0;start timing operation

; Acquire an unprocessed image with camera 1

     VPICTURE (cam) 2

; Locate sample object, calculate the tail point and object's rotation

     CALL line.line(tailx, taily, obj.rot, good_part)

; Call return program and get next part if point is not found
```

```
      IF NOT good_part THEN
          TYPE "The object was not found or was incorrectly positioned."
          CALL return_part()
      END ; if

;Use the coordinates of the object tail to set a processing window

      IF good_part THEN
          win_ibr = 3000;AOI 3
          VDEF.AOI win_ibr = 1, tailx-obj_width/2, taily, obj_width+5,
                                                            obj_hgt+15, obj.rot
          VWINDOW (cam) win_ibr

; Remove the object from the vision queue and make its characteristics
; available to the VFEATURE function.

          VLOCATE (cam, 2) "?", obj.loc

; Check to see if a part was successfully located.

          IF NOT VFEATURE(1) THEN
             TYPE "A hole was not located."
             CALL reject_part()
             good_part = FALSE
          END
      END ; if good_part

; Check that there are two holes in the part

      IF good_part THEN
          IF VFEATURE(17) <> 2 THEN
             TYPE "The part has an incorrect number of holes."
             CALL reject_part()
             good_part = FALSE
          END
      END ; if good_part

; Remove the holes from the queue and check their centroids.
; Remove the largest hole (the circle) from the queue.

      IF good_part THEN
          VLOCATE (cam, 4, 1) , rnd.loc

; Save the circle's centroid X and Y values

          cent_circlex = VFEATURE(2)
          cent_circley = VFEATURE(3)

; The next hole removed will be the polygon

          VLOCATE (cam, 4) , poly.loc

; Calculate the distance
```

```
        rnd_act = DISTANCE(obj.loc,rnd.loc)
        poly_act = DISTANCE(obj.loc,poly.loc)

; Compare the distances and reject part if they are not within .5mm of correct.

        IF ABS(rnd_act-rnd_dist) > 0.5 THEN
           TYPE "The round hole is out of alignment."
           CALL reject_part()
           good_part = FALSE
        END; if ABS

        IF ABS(poly_act-poly_dist) > 0.5 THEN
           TYPE "The polygon hole is out of alignment."
           CALL reject_part()
           good_part = FALSE
        END; if ABS
    END ; if good_part

; Place a ruler that starts at the center of the circular hole and
; goes past its edge.

    IF good_part THEN
        rul_ibr = 4000;AOI 4
        VDEF.AOI rul_ibr = 2, cent_circlex, cent_circley, 10, 0
        VRULERI (cam, 0, 1) circ_hole[] = rul_ibr

; Check the value of the first transition (which will be the radius)
; against the required value.

        IF circ_hole[0] == 0 THEN
           TYPE "The radius of the circular hole could not be determined."
        ELSE
           IF ABS((2*circ_hole[2])-circ_diam) > 1 THEN
               TYPE "The circular hole is not the correct size."
               CALL reject_part()
               good_part = FALSE
           END ; if ABS
        END    ; if circ_hole[0]
    END ; if good_part

; Place a VFIND.LINE tool at the center of the polygon, and have it
; look in the negative Y direction for an edge. Search from dark
; to light (object to background).

    IF good_part THEN
        lfdr_ibr = 5000;AOI 5
        VDEF.AOI lfdr_ibr = 1, VFEATURE(2), VFEATURE(3), 10, 10, obj.rot
        VFIND.LINE (cam, 0) poly_hole[] = lfdr_ibr

; Compare the actual value with the acceptable value
```

```
          IF ABS(poly_hole[4]-poly_angle) > 2 THEN
             TYPE "The poly shaped hole is incorrectly oriented."
             CALL reject_part()
             good_part = FALSE
          END; if ABS
      END ; if good_part

      IF good_part THEN

; Calculate the X,Y center point for the arc finder

          x = DX(obj.loc)
          y = DY(obj.loc)

;Use the locations of the two holes to calculate the midpoint

          arc.centx = (DX(rnd.loc)+DX(poly.loc))/2
          arc.centy = (DY(rnd.loc)+DY(poly.loc))/2

; Place an arc finder centered around the two holes and look from
; dark to light for an arc.

          afdr_ibr = 6000;AOI 6
          VDEF.AOI afdr_ibr = 5, x, y, obj_hgt/2, obj_hgt/2+5, 90+obj.rot,
                                                                  270+obj. rot
          VFIND.ARC (cam) arc_data[] = afdr_ibr

; Check to see if an arc was found

          IF NOT arc_data[0] THEN
             TYPE "The outer radius was not located."
             CALL reject_part()
             good_part = FALSE
          END; if not
      END ; if good_part

; Calculate the center variance

      IF good_part THEN
          IF ((ABS(arc_data[2]-arc_centx) > 100) OR (ABS(arc_data[3]-arc_centy)
                                                                    > 1)) THEN
             TYPE "The outer radius is not correctly aligned with the two
                                                                      holes."
             CALL reject_part()
             good_part = FALSE
          END; if ABS
      END ; if good_part

; Place a graylevel ruler along the width of the object, starting at
; object tail and ending 5mm from the edge of the object.
```

```
      IF good_part THEN
          grul_ibr = 7000;AOI 7
          VDEF.AOI grul_ibr = 1, tailx-5, taily, obj_width-10, 180+obj.rot
          VRULERI (1, 1) gray_data[] = grul_ibr

; Calculate the graylevel changes every 25 pixels and compare them
; with the acceptable value (gvalue).

          FOR i = 2 TO (gray_data[0]-25) STEP 25
              good_part = ABS(gray_data[i]-gray_data[i+25]/gvalue) > 0.9
              good_part = good_part AND (ABS((gray_data[i]-gray_data[i+25])
                                                              /gvalue < 1.1))

              IF NOT good_part THEN
                  CALL reject_part()
                  TYPE "Graylevel ruler failed."
                  GOTO 90;exit on failure
              END
          END     ; for i = 2
      END ;if good_part

; Read the timer

    90 cycle_time = TIMER(1)

; Calculate the total time.

      total_time = cycle_time+(avg_time*num_parts)
      IF good_part THEN
          num_parts = num_parts+1
      END
      IF num_parts == 0 THEN
          avg_time = 0
      ELSE
          avg_time = total_time/num_parts
      END

; Output the data to the vision window.

      $msg[0] = "Average Processing Time: "
      $msg[1] = $ENCODE(avg_time)
      $msg[2] = "Number of units passed: "
      $msg[3] = $ENCODE(num_parts)

; Get the mm/pixel ratio and divide the screen into 20 lines

      VGETCAL (cam) cal[]
      hgt = cal[16]*480;Screen height in millimeters
      inc = hgt/20

; Start at the first line and indent text one line

      x = inc
      y = inc
```

```
     FOR i = 3 TO 0 STEP -1
         CALL write.vwin(cam, x, y, $msg[i], $err)
         y = y + inc

         IF $err <> "" THEN
             TYPE $err;Output error message
             EXIT
         END
     END

; Read timer 2 to see how long it has been since the threshold was set.
; If it exceeds 30 minutes, set V.THRESHOLD and restart timer 2.

     ttime = TIMER(2)
     IF ttime > 1800 THEN
         VWAIT;make sure the processor is idle
         VAUTOTHR tarray[]
         IF tarray[0] THEN
             PARAMETER V.THRESHOLD = tarray[1]
         END; if
         TIMER 2 = 0
     END ; if

.END
```

Subroutine - line.line

```
.PROGRAM line.line(x, y, tool.ang, status)

;
; ABSTRACT: This program uses data from two line finder tools to calculate
;       the intersection of two lines, and the angle of a line bisecting
;       the intersection point (used to place other tools). The current frame
;       store must have a valid image.
;
; INPUT PARM: None
;
; OUTPUT PARMS:  x - x coordinate of the intersection point
;       y - y coordinate of the intersection point
;       tool.ang - angle of a line bisecting the intersection point
;       status - success of operation
;
; SIDE EFFECTS: None
;

     LOCAL ang.t, xt, yt, dxt, dyt;top line data
     LOCAL ang.b, xb, yb, dxb, dyb;bottom line data
     LOCAL obj.ang;angle between sides of the object
     LOCAL aoi1, aoi2

     status = TRUE;assume lines are found

; Place the two line finders

     aoi1 = 1001
     aoi2 = 2001
     VDEF.AOI aoi1 = 1, 110, 80, 40, 30, 150
     VDEF.AOI aoi2 = 1, 110, 50, 40, 30, 30
     VFIND.LINE (1) top[] = aoi1
     VFIND.LINE (1) bottom[] = aoi2

; Check to see if both lines were found

     IF NOT (top[0] AND bottom[0]) THEN
         status = FALSE;return failure in status
         GOTO 100
     END

; Extract the line finder data

     ang.t = top[4]
     ang.b = bottom[4]
     dxt = COS(ang.t)
     dyt = SIN(ang.t)
     dxb = COS(ang.b)
     dyb = SIN(ang.b)
     xt = top[2]
     yt = top[3]
     xb = bottom[2]
     yb = bottom[3]

; Calculate the rotation of the object

     obj.ang = ang.b+180-ang.t
     tool.ang = ang.b-(obj.ang/2)

; Calculate the intersection point

     numerator = (yb-yt)*dxb-(xb-xt)*dyb

     IF ABS(dxt) > ABS(dyt) THEN
         fract = dyt/dxt
         f = numerator/(fract*dxb-dyb)
         x = xt+f
         y = yt+fract*f
     ELSE
         fract = dxt/dyt
         f = numerator/(dxb-fract*dyb)
         y = yt+f
         x = xt+fract*f
     END

   100 ;Exit on failure

.END
```

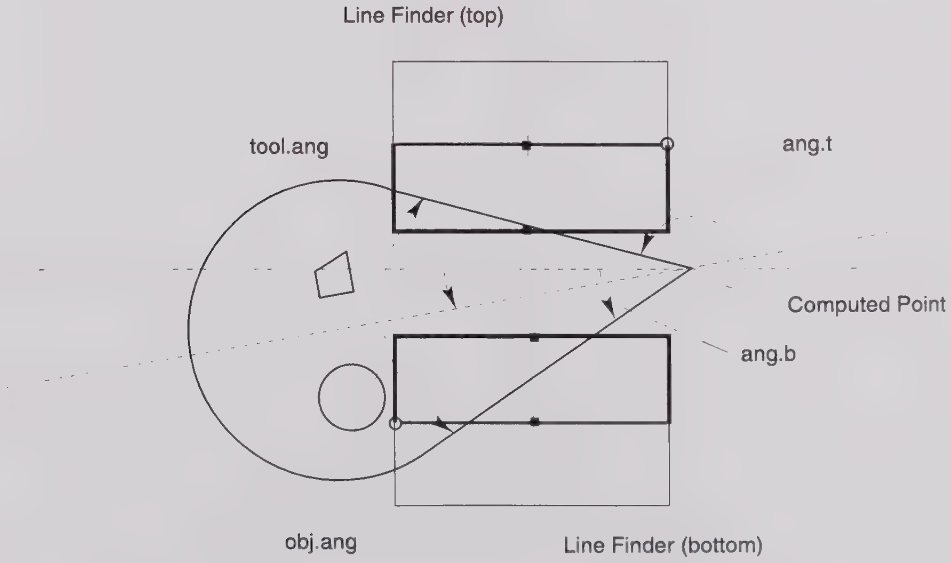

Line Finder (top)
tool.ang
ang.t
Computed Point
ang.b
obj.ang
Line Finder (bottom)

Figure 12-5. Calculating the Object Tail Location

Subroutine - init.program

```
.PROGRAM init.program(cam)

; ABSTRACT: This program initializes the cycle time statistics and camera
;        environment.
;
; INPUT PARMS:    cam   virtual camera being used
;
; OUTPUT PARMS:   None
;
; GLOBAL VARS:  to.cam, thresholds[], cam.cal[], $err
;
; SIDE EFFECTS: If the global variables avg_time, total_time, and num_parts
;       are not defined, they are set to 0
;

     num_parts = 0
     avg_time = 0
     total_time = 0

; Load calibration data.  load.area is supplied on the utility disk in the
; file LOADAREA.V2.  See the "Instructions for Adept Utility Programs" for
; details on the calling sequence.

     CALL load.area("area87.dat", cam, thresholds[], TRUE, to.cam, cam.cal[],
                                                                       $err)

; Reset the timer used to determine when to recalculate V.THRESHOLD

     TIMER (2) = 0

; Set the binary threshold

     VAUTOTHR thresholds[]
     IF thresholds[0] THEN
         PARAMETER V.THRESHOLD = thresholds[0]
     ELSE
         TYPE "A threshold could not be computed. Check the lens aperture
                                                                 setting."
     END

.END
```

Subroutine - write.vwin

```
.PROGRAM write.vwin(cam, x, y, $text, $err)

; ABSTRACT: This program demonstrates how to use the millimeter scaling mode of
; GTRANS to label an object in the vision window.
;
; INPUT PARM: cam   virtual camera number (REAL variable)
;   x, y    location of text on vision screen (REAL variable)
;   $text   text containing (STRING variable)
;
; OUTPUT PARM: $err   string containing error messages

      AUTO vlun

      $err = "";Assume no error

; Attach and open the vision window

      ATTACH (vlun, 4) "GRAPHICS"
      IF (IOSTAT(vlun) < 0) OR (vlun == -1) GOTO 100

      FOPEN (vlun) "Vision";Open the vision window
      IF IOSTAT(vlun) < 0 GOTO 100

; Select display mode, color, and graphics mode

      VDISPLAY (cam) 1, 1;Display grayscale frame and graphics

      GCOLOR(vlun) 1;Select the color black
      GTRANS (vlun, 1);Select millimeter scaling

; Output the text to the screen at the desired location

      GTYPE(vlun) x, y, $text, 3

; Detach from the logical unit (frees up the communications path)

      DETACH (vlun)

; Check for errors

100   IF (IOSTAT(vlun) < 0) THEN
          $err = $ERROR(IOSTAT(vlun))
      END
      IF vlun == -1 THEN
          $err = "All logical units are in use."
          PAUSE
      END

.END
```

Guidance Vision

13

Introduction 224
Using a Fixed-Mount Camera 225
4-Axis SCARA Robot with Camera on Link #2 229
5-Axis SCARA Robot with Camera on Link #2 234
5-Axis SCARA Robot with Camera on Link #2 234
Guidance Vision Program 236
    The Sample Program 237
Further Programming Considerations 246
    Error Handling 246
    Generalizing the Program 246

Introduction

Before a camera can be used for inspection or guidance vision, the camera must be calibrated and the calibration data must be transferred to the vision system. Cameras are normally calibrated using the advanced camera calibration utility. See Chapter 4 for details. Once you have calibrated a camera and stored the calibration data to a disk, the calibration data can be loaded from disk using the LOADAREA utility program (on the Adept Utility Disk #1). See the sample program on page 220 for an example. (Camera calibration data must be reloaded each time the controller is turned off or system memory is zeroed. See "Loading Vision Calibration Data" on page 57.)

One element of the camera-to-robot calibration relates the vision coordinate frame (see Figure 13-1) to the world coordinate system of the robot. The vision system returns X and Y coordinates and RZ rotation defining the location and orientation of an object with respect to the vision coordinate system. This information is combined into a transformation value that represents an object's location in world coordinates. This section describes how to use the two most common camera mountings: fixed-mount camera and cameras mounted on the second link of several common robot types. Additional camera mountings are described in the camera calibration user's guide.

Using a Fixed-Mount Camera

A fixed-mount camera is any camera that acquires images at a fixed location in the robot workspace.

The following code will locate a “blob” and then move the robot to the blob’s location:

```
.PROGRAM pickup.part.fix (); pick up part with fixed camera

; ABSTRACT: The following sample program is used to:
;1) Move to a  location outside the camera field of view
;2) Locate a single part using blob recognition
;3) Acquire the part with a single pneumatic gripper (vacuum or mechanical)
;4) Raise the part 50 mm
;
; COMMENTS: In order for this program to run, a location called "pic.loc" must
;already exist. When the robot is at pic.loc, the part must be in the
;camera's field of view and not obstructed by the robot.

    LOCAL obj.loc, part.loc, vis.loc, $ret

    MOVE pic.loc; Move to picture taking location
    BREAK    ; Stop robot

    VPICTURE (1)  -1; Take picture with camera 1

    VLOCATE(1, 0) $name, vis.loc    ; Find single object in field of view
                                    ; with Blob recognition

    SET obj.loc = to.cam[1]:vis.loc:RZ(VFEATURE(48))  ; Determine the location
                                                      ; and orientation of the
                                                      ; part in world
                                                      : coordinates

; Transformation to.cam[1] is generated by the Advanced Camera Calibration
; Utility Program and loaded by the utility LOADAREA.V2 on the Adept Utility
; Disk

    IF NOT DEFINED (grip.trans) THEN

; If it is necessary to reteach the "grip.trans" transformation, the existing
;"grip.trans" transformation must be deleted at the system prompt by typing
;DELETEL GRIP.TRANS before executing this program.

      DETACH(0); Detach robot so pendant can be used

      TYPE " Using the pendant, place the gripper on the part to pick it up"
      TYPE " Once the robot is in position, Hit COMP/PWR on the pendant"
      PROMPT " and hit return on the keyboard ", $ret
```

```
        HERE obj.loc:grip.trans
        ATTACH(0); Reattach robot

    END

    SET part.loc = obj.loc:grip.trans  ;Complete transformation to pick up
                                       ;part.  part.loc should have pitch of
                                       ;180. Check by typing LISTL part.loc

    APPRO part.loc, 50                 ; Approach part by 50 mm
    BREAK                              ; Stop robot

    MOVE part.loc                      ; Move to part
    BREAK
    CLOSEI                             ; Close gripper or turn on vacuum

    DEPART 50                          ; Move part up 50 mm
    BREAK

.END
```

The location variables in the preceding code are calculated as follows:

to.cam [1]	is the camera calibration transformation for virtual camera 1.
vis.loc	is the vision location returned by the VLOCATE instruction.[1] The transformation returned by boundary analysis has a rotation the same as the vision coordinate frame. The axis of least inertia (returned by VFEATURE(48)) is used to calculate the location orientation.
grip.trans	is the grip transformation for the part. Since the vision system can calculate location data only in a two-dimensional plane, an additional transformation must be defined to account for the Z component of the final world location (and possibly the gripper rotation necessary for grasping a part).

CAUTION: A new grip transformation should be defined whenever new calibration data is computed. Failure to use a valid grip transformation could cause the robot to run into the part or the work surface when moving to a location determined from a vision image.

---

[1] The vision location (vis.loc) can be created by any vision operation(s) that returns information that can be used to calculate a transformation representing the location of an object within the vision coordinate system. The remainder of this chapter and the next chapter describe vision operations that return location data.

part.loc is the compound transformation based on the vision location (vis.loc), the camera calibration transformation (to.cam), and the grip transformation. This transformation represents the part location in world coordinates.

Figure 13-1 shows the components of the vision transformation, “to.cam”, “vis.loc”, and “grip.trans”.

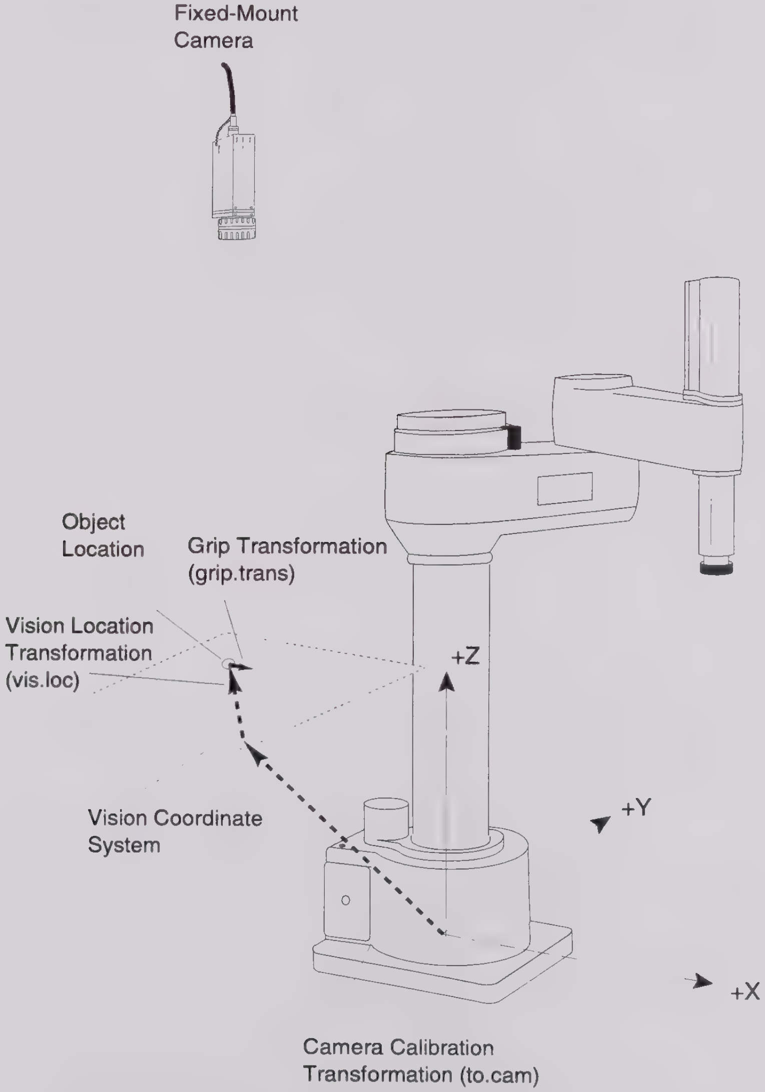

Fixed-Mount Camera
Object Location
Grip Transformation (grip.trans)
Vision Location Transformation (vis.loc)
+Z
+Y
Vision Coordinate System
+X
Camera Calibration Transformation (to.cam)

Figure 13-1. Fixed-Mount Camera (Vision Location)

Figure 13-2 shows all the components of the vision transformation, plus the resulting compound transformation, "part.loc".

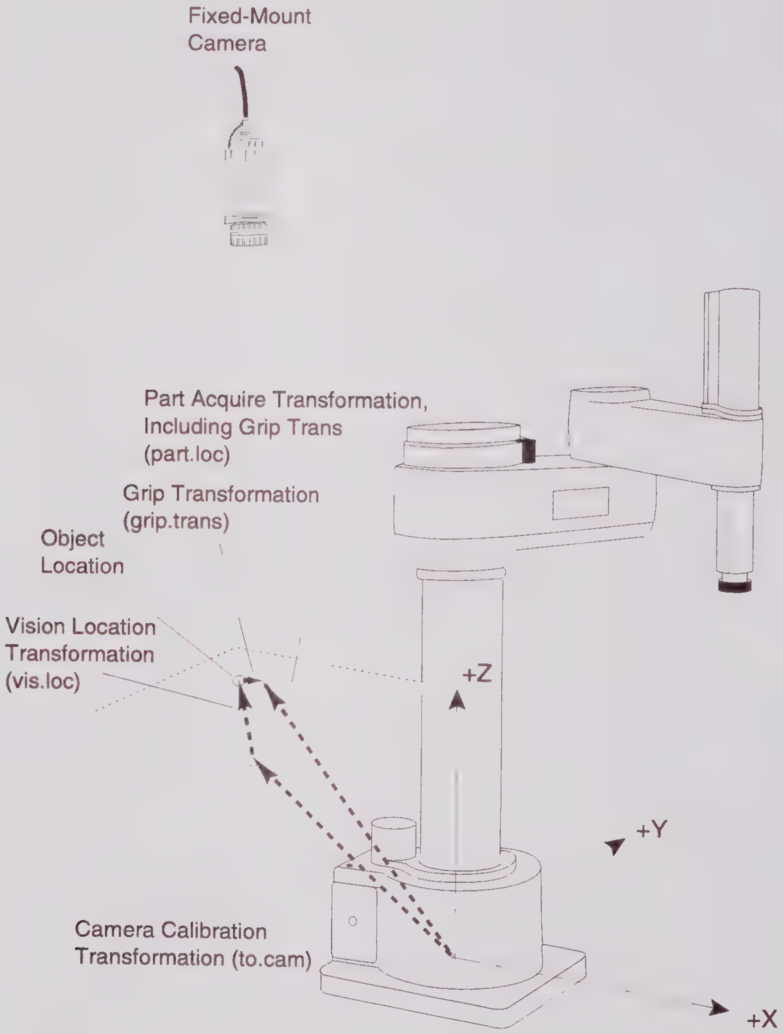

Fixed-Mount
Camera
Part Acquire Transformation,
Including Grip Trans
(part.loc)
Grip Transformation
(grip.trans)
Object
Location
Vision Location
Transformation
(vis.loc)
+Z
+Y
Camera Calibration
Transformation (to.cam)
+X

Figure 13-2. Fixed-Mount Camera Vision Transformation

4-Axis SCARA Robot with Camera on Link #2

The instructions in this section will work for a camera mounted on SCARA, XY, XYZ, or XYZ-Theta type robots. The strategies shown in this section can be extended to define a guided vision application with the camera mounted on any axis of a motion device.

When you use a robot-mounted camera, the camera calibration transformation defines the location of the vision coordinate frame relative to the robot link on which the camera is mounted. In order to use location information from the vision system, you must know the relationship between the link holding the camera and the robot world coordinate system.

For a camera mounted on the robot, we conceptually break down the robot into a series of "links" connected by "joints". Each link can be considered as having its own coordinate system. For example, the world coordinate system is the same as the coordinate system of the base of the robot (link #0). For Adept SCARA robots, the origin of the world coordinate system is on the joint-1 axis at the level of the robot base.

The "outer" link of an Adept SCARA robot is link #2. (Figure 13-3 shows the "link2" coordinate frame.) We define the coordinate system for link #2 as follows:

- The origin is fixed relative to the outer link, at the center of the quill, at the height of the quill flange when joint 3 is at its zero position.
- The Z axis points down.
- The X axis points away from joint #2, as if it is an extension of the outer link.

The following program shows how to locate and acquire a part with a camera mounted on link #2.

```
.PROGRAM pickup.part.lk2(); pick up part with link 2 camera

; ABSTRACT: The following sample program is used to:
;   1) Move to a  picture-taking location
;   2) Locate a single part using blob recognition
;   3) Acquire the part with a single pneumatic gripper (vacuum or mechanical)
;   4) Raise the part 50 mm
;
; COMMENTS: In order for this program to run, a location called "pic.loc" must
;       already exist. When the robot is at pic.loc, the part must be in the
;       camera's field of view.

    LOCAL jt[], link2, obj.loc, part.loc, vis.loc, $ret
    MOVE pic.loc; Move to picture-taking location
    BREAK   ; Stop robot

    DELAY 0.1                     ; Let camera settle for 0.1 seconds
    BREAK

    HERE #pic.loc; Create a precision point at pic.loc

    VPICTURE (1)  -1; Take picture with camera 1

    VLOCATE(1, 0) $name, vis.loc  ; Find single object in field of view
                                  ; with Blob recognition

    DECOMPOSE jt[1]=#pic.loc      ; Obtain joints values at #pic.loc for
                                  ; use in building part location
                                  ; transformation

    SET link2=HERE:RZ(-jt[4]):TRANS(,,-jt[3]); Develop first part of object
                                  ; transformation

    SET obj.loc = link2:to.cam[1]:vis.loc:RZ(VFEATURE(48)) ; Develop world
                                  ; location of object

; Transformation to.cam[1] is generated by the Advanced Camera Calibration
; Utility Program and loaded by the utility LOADAREA.V2 on the Adept Utility
; Disk

    IF NOT DEFINED (grip.trans) THEN

; If it is necessary to reteach the "grip.trans" transformation, the
; existing "grip.trans" transformation must be deleted at the system prompt
; by typing DELETEL GRIP.TRANS before executing this program.

      DETACH(0); Detach robot so pendant can be used

      TYPE " Using the pendant, place the gripper on the part to pick it up"
      TYPE " Once the robot is in position, Hit COMP/PWR on the pendant"
      PROMPT " and Hit return on the Keyboard", $ret

      HERE obj.loc:grip.trans
      ATTACH(0); Reattach robot

    END

    SET part.loc = obj.loc:grip.trans; Complete transformation to pick up
                                  ; part. part.loc should have pitch of 180.
                                  ; Check by typing LISTL part.loc

    APPRO part.loc, 50            ; Approach part by 50 mm
    BREAK                         ; Stop robot
    MOVE part.loc; Move to part
    BREAK
    CLOSEI                          ; Close gripper or turn on vacuum
    DEPART 50                       ; Move part up 50 mm
    BREAK

.END
```

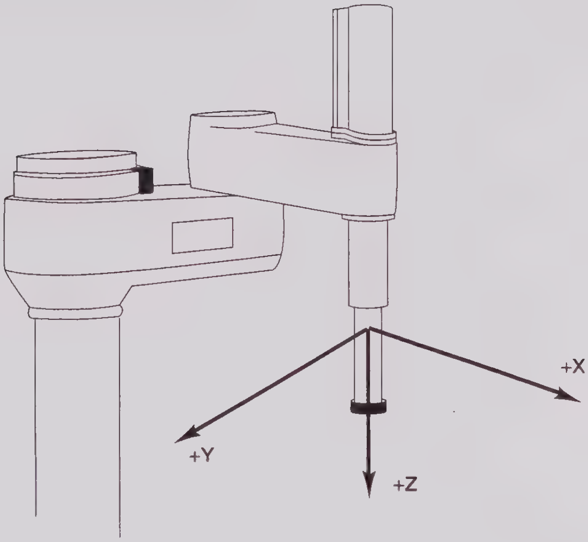
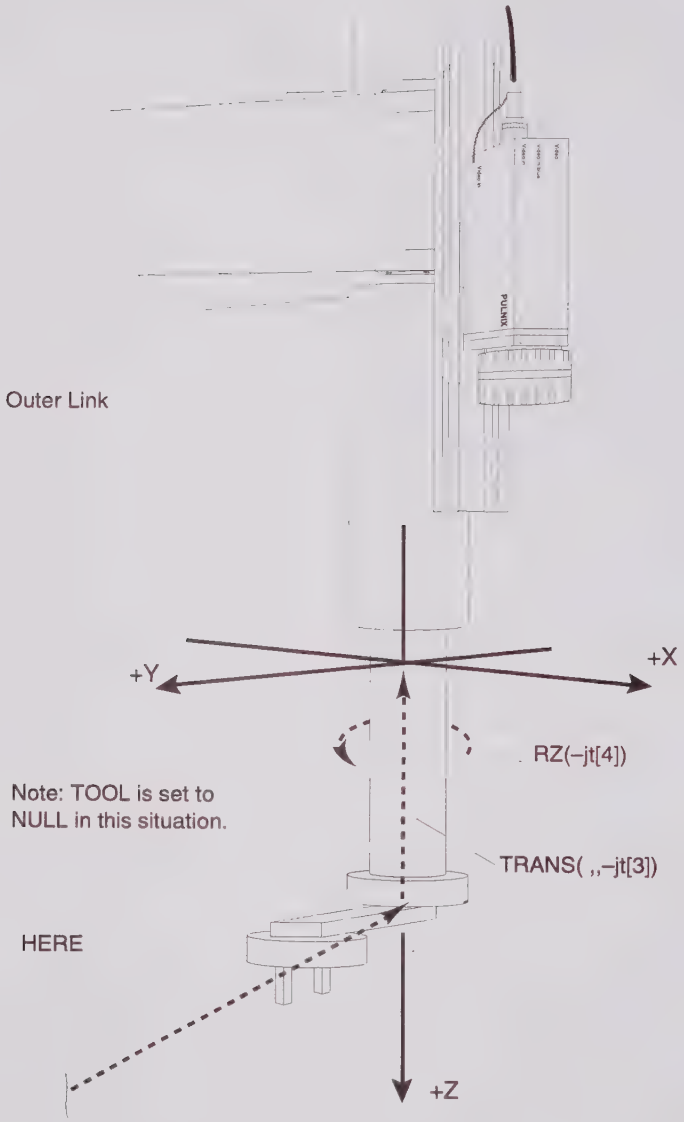


Figure 13-3. Link2 Coordinate Frame

Figure 13-4 shows the link transformation, "link2", that was calculated by the preceding program instructions. The program instruction HERE creates a transformation in world coordinates that represents the current tool tip. RZ(–jt[4]) removes any rotation of joint4 from the resulting transformation. TRANS(,,–jt[3]) removes any quill extension from the transformation. Note: the preceding program and Figure 13-4 assume that a NULL TOOL is invoked. If a NULL TOOL is not used, then the link transformation (last code line on page 230) should be changed to:

```
SET link2 = HERE:INVERSE(TOOL):RZ(-jt[4]):TRANS(,,-jt[3])
```



Note: TOOL is set to NULL in this situation.

Figure 13-4. Calculating the “Link2” Transformation

Since the camera calibration transformation was created based on the link2 coordinate frame, any time you use the camera calibration transformation (“to.cam” in this example), it must be applied to the link2 coordinate frame.

Note that the value of “link2” must be computed from the robot’s location when the vision image is acquired. Thus, the instructions above will have to be executed each time a picture is taken at a new location.

Figure 13-5 shows how the remaining components of the location are calculated. "link2" was calculated as shown in Figure 13-4. "to.cam [1]" (created during camera calibration) is added to create a transformation relating the vision coordinate system to the world coordinate system. "vis.loc" (returned by a vision operation—blob recognition in this case) is added to create a transformation that represents the location of the found part in the XY plane of the vision coordinate system. RZ(VFEATURE(48)) is added to give the orientation of the part. "grip.trans" is added to create a transformation that offsets and/or rotates the gripper if the found object is to be acquired at a location offset or rotated from the location returned by the vision operation.

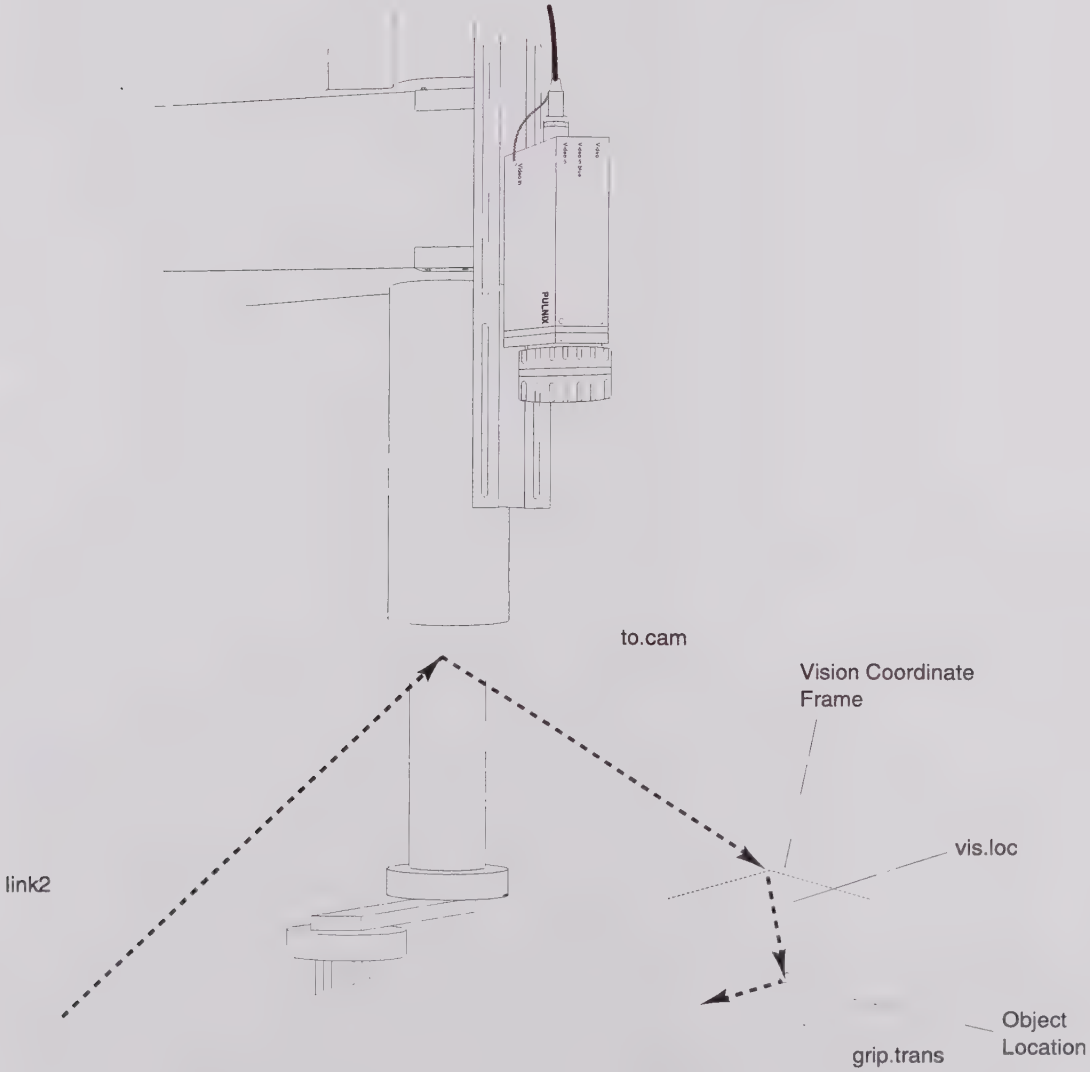


Figure 13-5. Components of the Vision Location

Figure 13-6 summarizes the transformations used when calculating the final part acquire location.

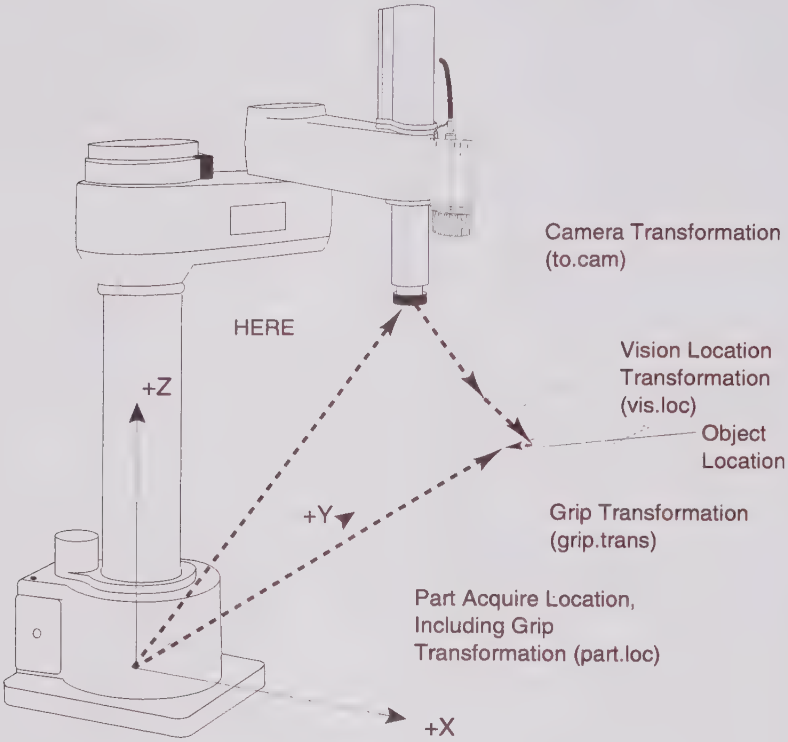

Camera Transformation (to.cam)
HERE
Vision Location Transformation (vis.loc)
+Z
Object Location
+Y
Grip Transformation (grip.trans)
Part Acquire Location, Including Grip Transformation (part.loc)
+X

Figure 13-6. Final Part Acquire Location

5-Axis SCARA Robot with Camera on Link #2

If a fifth axis (see Figure 13-7) is attached to an Adept SCARA Robot (AdeptOne and AdeptThree) we now have another joint that must be accounted for when we calculate the "link2" coordinate frame. When a fifth axis is mounted on the robot, the kinematic model automatically sets the null tool from the normal position at the end of joint three (the tool flange) to the pivot point of the fifth axis. However, the fifth axis has an additional offset from the pivot point to the new tool flange that needs to be nulled in the "link2" transformation. The dimension of this offset is 50mm. Starting at the end of the robot the procedure is as follows: Find the current location of the end-effector "HERE", null any tool transformation currently in effect "INVERSE(TOOL)", null the offset along the negative tool Z axis "TRANS(,,–50)", null the rotation of the fifth axis (rotation about the local Y axis) "RY(–jt[5])", null the rotation of joint 4 (rotation about the local Z axis) "RZ(–jt[4])", null the height of joint 3 "TRANS(,,–jt[3])". Use the "link2" transformation below when working with a fifth axis and the camera mounted on link #2.

```
SET link2 =
HERE:INVERSE(TOOL):TRANS(,,-50):RY(-jt[5]):RZ(-jt[4]):TRANS(,,-jt[3])
```

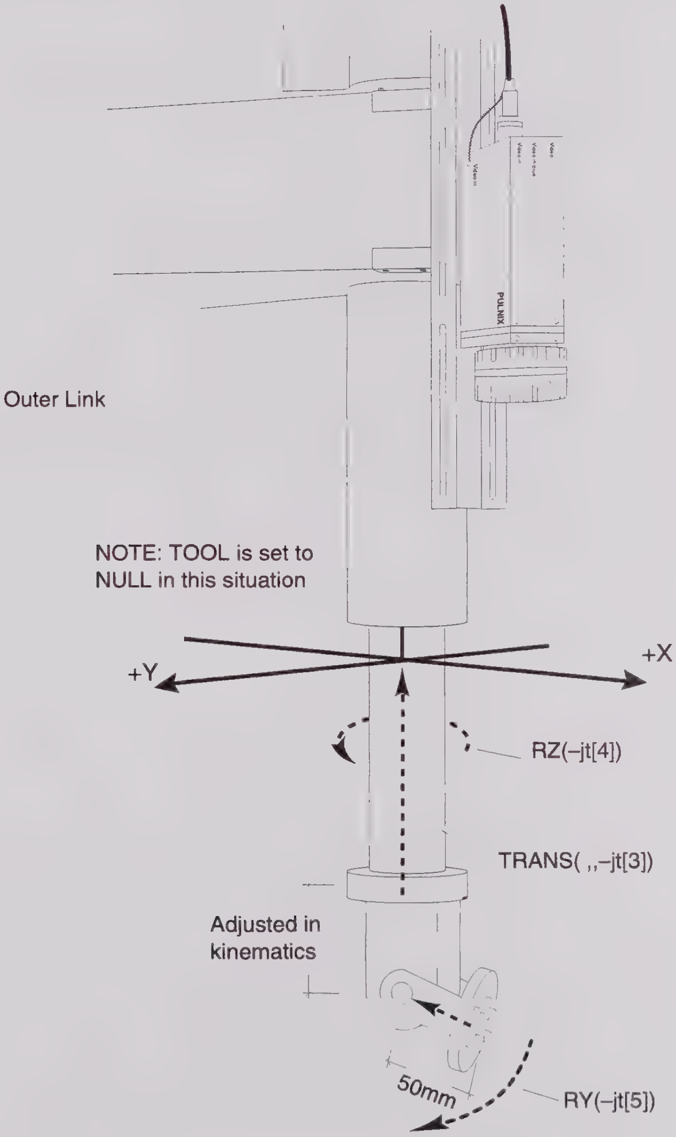

Outer Link
NOTE: TOOL is set to NULL in this situation
+Y
+X
RZ(–jt[4])
TRANS(,,–jt[3])
Adjusted in kinematics
50mm
RY(–jt[5])
PULNIX

Figure 13-7. Five-Axis Vision Transformation

Guidance Vision Program

This section details the development of an AdeptVision VXL guidance vision program. The program includes vision instructions that were presented in previous chapters as well as other V^+ program instructions. As you go through this example, remember that we are not attempting to present the most efficient guidance vision application. We are attempting to present examples of vision instructions in a simple, straightforward context.

This example assumes that you are familiar with basic V^+ programming. All the commands presented in this example are detailed in the *V^+ Language Reference Guide* or the *AdeptVision Reference Guide.*

The program listed below will pick up round parts from one conveyor belt and palletize them to pallets on another conveyor belt. The parts will be randomly located on the conveyor belt. An arm-mounted camera will be used to locate the parts and guide the robot to pick them up. Both conveyor belts are "indexing" belts and will be started and stopped using digital I/O signals.

After each part is picked up, it will be presented to a fixed-mount, upward-looking camera for inspection. If the part passes inspection, it will be palletized. Otherwise, it will be taken to a scrap bin.

The conveyor belt carrying the pallets holds the pallets rigidly in parallel with the robot X axis so no X axis correction is necessary. The pallets are also rotationally rigid so no rotation correction is necessary. There is some variance in the absolute Y location. This variance is calculated using a fixed-mount, downward-looking camera. Figure 13-8 shows the physical setup for this workcell.

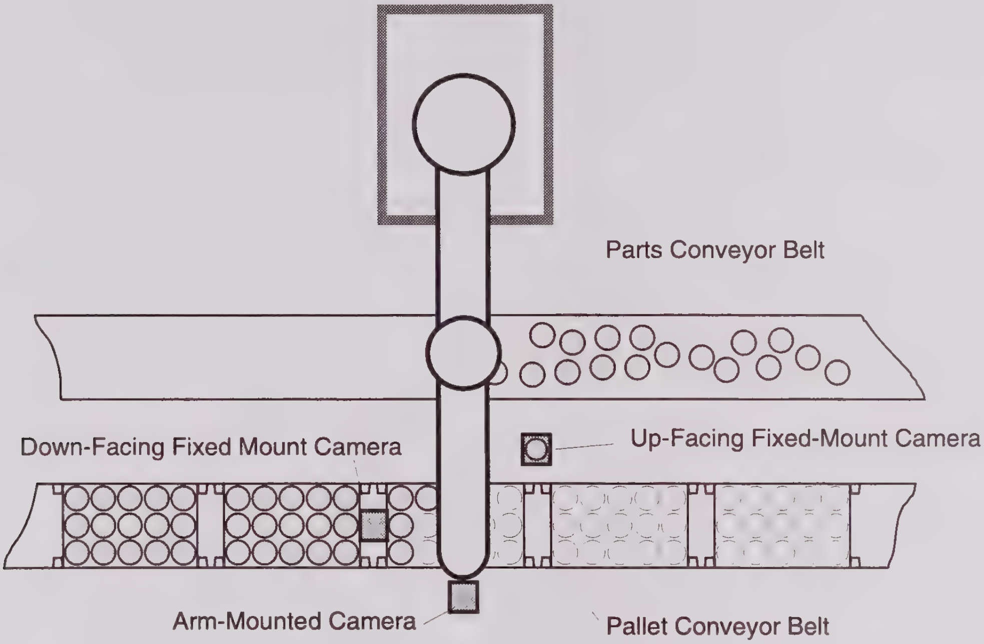


Figure 13-8. Example Program Setup

The Sample Program

```
.PROGRAM guided.vis.examp()

; ABSTRACT: This program implements a robot workcell that:
;   1) Allows teaching of workcell locations if necessary,
;   2) Visually locates parts brought into the workcell on an
;      indexing conveyor,
;   3) Picks up the parts and presents them to a camera for inspection,
;   4) Discards the part if it fails, or palletizes it if it passes.
;   The program will also load camera calibration files that have
;   been previously stored on the default disk.
;
; INPUT PARMS:  None
;
; OUTPUT PARMS: None
;
; SIDE EFFECTS: The following global variables are set:
;   pallet.loc - location of row 1, col 1 on the pallet
;   pallet.frame - reference frame for the pallet
;   inspect.loc - location robot presents part to up-mounted camera
;   pic.loc - location robot takes picture of incoming part
;   scrap.loc - location robot takes rejected parts
;   arm.cam - number of the arm-mounted camera (locates parts)
;   up.cam - number of the upward-looking camera (inspects parts)
;   dwn.cam - number of the downward-looking camera (locates pallets)
;   di.oper - input signal controlling main processing loop
;   di.part.ready - input signal indicating a part is ready
;   di.pallet.ready - input signal indicating a pallet is ready
;   do.pal.belt - output signal driving the pallet conveyor
;   do.part.belt - output signal driving the parts conveyor
;

    AUTO row, col, max.rows, max.cols, row.dist, col.dist
    AUTO passed, num.parts
    AUTO $ans
    AUTO gripz
    AUTO i

; Initialize variables

    arm.cam = 1
    dwn.cam = 2
    up.cam = 3
    di.oper = 1001
    di.part.ready = 1002
    di.pallet.ready = 1003
    do.pal.belt = 5
    do.part.belt = 6

    passed = FALSE  ;Assume the part failed inspection
    row = 1
    col = 1
    max.rows = 3    ;The pallet is 3x5
    max.cols = 5
    row.dist = 50   ;Spacing of pallet locations
    col.dist = 50
    ENABLE UPPER

; Check to see if camera cal data is loaded - load if necessary

    IF NOT DEFINED(to.cam[1]) THEN
        CALL load.cam.cal()
    END

; Should the operator create new robot locations?

    DO
        PROMPT "Do you want to teach new robot locations? ", $ans
    UNTIL ($ans == "y") OR ($ans == "n")

    IF $ans == "y" THEN

; Get the first pallet

        SIGNAL do.pal.belt
        TYPE "Waiting for pallet."
        WAIT SIG(di.pallet.ready)
        SIGNAL -do.pal.belt
```

```
; Teach the robot locations

        CALL teach.pallet(max.rows, max.cols, pal.offset, gripz)

    ELSE

; Bring in a new pallet and update the pallet location

        CALL new.pallet(pal.offset, pal.correction)
        SET cur.frame = SHIFT(pallet.frame BY ,pal.correction)

    END


; Start up the workcell

    TYPE /C1
    PROMPT "Turn on the RUN switch and press ENTER when ready to begin.", $ans
    WAIT SIG(di.oper)

    WHILE SIG(di.oper) DO

; Move to the picture-taking location and settle the robot

        MOVE pic.loc
        DELAY 0.2
        BREAK

; Bring parts into the workcell

        SIGNAL do.part.belt
        TYPE "Waiting on a part."
        WAIT SIG(di.part.ready)
        SIGNAL -do.part.belt
;Create the variables for determining the link2 coordinate frame

        HERE #pic.loc
        DECOMPOSE jt[1] = #pic.loc
        VPICTURE (arm.cam) -1, 0

; Make sure vision processor is idle, then determine how many parts are seen

        VWAIT
        num.parts = VQUEUE(arm.cam,"?")

; Locate the parts and palletize them

        FOR i = 1 TO num.parts
            VLOCATE (arm.cam, 2) "?", vis.loc

; Calculate the object location in world coordinates

            SET link2 = pic.loc:RZ(-jt[4]):TRANS(,,-jt[3])
            SET part.loc = link2:to.cam[1]:vis.loc:TRANS(,,gripz,,180)

; Pick up the part

            APPRO part.loc, 50
            OPENI
```

```
.PROGRAM load.cam.cal()

; ABSTRACT:  This program loads the camera calibration data for three
;   cameras. The calibration files must have been created and stored
;   on the default disk. Global variables arm.cam, dwn.cam, and up.cam
;   must have been previously defined.
;
; INPUT PARM:  None
;
; OUTPUT PARM: None
;
; SIDE EFFECTS: The array elements to.cam[1] - to.cam[3] are updated and three
;   virtual cameras are readied for use.
;
    LOCAL $arm.cal, $dwn.cal, $up.cal
    LOCAL $arm.dat, $dwn.dat, $up.dat

; Get the calibration data file numbers

    TYPE /C24, /U20
    PROMPT "What is the calibration number for the arm-mounted camera? ", $arm.dat
    PROMPT "What is the calibration number for the down-mounted camera? ", $dwn.dat
    PROMPT "What is the calibration number for the up-mounted camera? ", $up.dat

    $arm.cal = "area"+$arm.dat+".dat"
    $dwn.cal = "area"+$dwn.dat+".dat"
    $up.cam = "area"+$up.dat+".dat"

; Load the calibration files. See the "Instructions for Adept Utility Programs"
; for details on 'load.area'.

    CALL load.area($arm.cal, arm.cam, VAL($arm.dat), TRUE, to.cam[1], arm.cam. cal[],
                                                                          $error)
    CALL load.area($dwn.cal, dwn.cam, VAL($dwn.dat), TRUE, to.cam[2], dwn.cam. cal[],
                                                                          $error)
    CALL load.area($up.cal, up.cam, VAL($up.dat), TRUE, to.cam[3], up.cam.cal[],
                                                                          $error)

.END
```

```
.PROGRAM new.pallet(orig.offset, correction)

; ABSTRACT: This program monitors the proper digital I/O to bring a new
;   pallet into the workcell. When a pallet is in place, a line finder
;   calculates the new pallet correction factor.
;
; INPUT PARM: orig.offset   the offset that was calculated when the pallet
;             reference frame was originally taught.
;
; OUTPUT PARM: correction   the difference between the location of the
;             original pallet and the current pallet.

; Bring the pallet into the workcell

    SIGNAL do.pal.belt
    TYPE "Waiting for pallet."
    WAIT SIG(di.pallet.ready)
    SIGNAL -do.pal.belt

; Locate the edge of the current pallet and calculate the difference
; between it and the original pallet.

    VDISPLAY (dwn.cam) -1, 1
    VPICTURE (dwn.cam) 2
    VDEF.AOI 2000 = 1, 100, 150, 50, 25, 180
    VFIND.LINE (dwn.cam) data[] = 2000

    correction = data[3]-orig.offset

.END
```

```
.PROGRAM teach.pallet(rows, cols, pal.offset, gripz)

; ABSTRACT: This program teaches all the locations required by the
;   palletizing workcell. It creates a reference frame for the pallet and
;   calculates the Z offset for parts being acquired based on arm-mounted
;   camera data.
;
; INPUT PARMS: rows    number of rows in the pallet
;   cols    number of columns in the pallet
;
; OUTPUT PARMS: pal.offset    offset from the vertical edge of the field
;                             of view to the edge of a pallet.
;   gripz   the Z value for the grip transformation used to acquire
;             parts based on arm-mounted camera data.

; SIDE EFFECTS: The following global locations are updated:
;   pallet.loc - reference frame for the pallet
;   pic.loc - picture taking location for acquiring a part
;   inspect.loc - picture taking location for part inspection
;   scrap.loc - part reject location
;   pallet.frame - reference frame for the pallet

    AUTO fr.origin, fr.posx, fr.posy ;pallet frame locations
    AUTO $ans
    AUTO jt[], data[]

; Get the three locations required to establish a pallet reference frame.

    DETACH ()
    TYPE /C24, /U20, "Create the pallet reference frame."
    TYPE "Place the robot at the row 1, col 1 location on the pallet."
    PROMPT "Press ENTER when ready. ", $ans
    HERE fr.origin

    TYPE /C2, "Place the robot on the row 1, col ", rows," location."
    PROMPT "Press ENTER when ready. ", $ans
    HERE fr.posx

    TYPE /C2, "Place the robot in the row ", rows, " col ", cols," location."
    PROMPT "Press ENTER when ready. ", $ans
    HERE fr.posy

; Create the pallet frame

    SET pallet.frame = FRAME(fr.origin,fr.posx,fr.posy,fr.origin)

; Return to the frame origin and create the row1, col1 pallet location (relative
; to 'pallet.frame').

    TYPE "Enable 'COMP' mode.";Make sure comp mode is selected
    PROMPT "The robot will return to the frame origin. Press ENTER.", $ans
    ATTACH ()
    SPEED 20 ALWAYS          ;Slow down while in teach routine
    DEPART 50
    APPRO fr.origin, 50
    MOVE fr.origin
    BREAK
    HERE pallet.frame:pallet.loc
    DEPART 50
    SPEED 100
    DETACH ()

; Create the part acquire picture-taking location

    TYPE /C2, "Establish the part acquire picture-taking location."
    VPICTURE (arm.cam) 2
    VDISPLAY -1, 1
    TYPE "Place the robot at the picture-taking location."
    PROMPT "Press ENTER when ready. ", $ans
    HERE pic.loc

; Create the part inspect picture-taking location

    TYPE /C2, "Establish the part inspect picture-taking location."
    VPICTURE (up.cam) 2
    VDISPLAY -1, 1
    TYPE "Place the robot at the picture taking location."
    PROMPT "Press ENTER when ready. ", $ans
    HERE inspect.loc

; Create the part reject location

    TYPE /C2, "Establish the part reject location."
    TYPE "Place the robot at the reject location."
    PROMPT "Press ENTER when ready. ", $ans
    HERE scrap.loc

; Calculate the Z offset for the grip transformation
; (A NULL TOOL is assumed, and no grip offset from the center of the part is
; needed.)

    TYPE /C2, "Establish the nominal part pickup location."
    TYPE "Place a sample part in the field of view and grip it with the robot."
    PROMPT "Press ENTER when ready.", $ans

; The grip trans will be added to the transformation composed of the link2
; coordinate frame and the camera calibration location.

    HERE #part.nom
    DECOMPOSE jt[1] = #part.nom
    SET link2 = HERE:RZ(-jt[4]):TRANS(,,-jt[3])
    HERE link2:to.cam[1]:part.loc
    ATTACH ()

;Extract the Z offset for the part

    gripz = DZ(part.loc)

;Determine the nominal offset of the pallet

    VPICTURE (dwn.cam)
    VDEF.AOI 6000 = 1, 100, 150, 50, 25, 180
    VFIND.LINE (2) data[] = 6000
    pal.offset = data[3]
.END
```

Further Programming Considerations

Error Handling

In the interest of presenting clear examples, several necessary steps have been left out of this program. The most basic missing steps are error handling and data validation. The data arrays returned by the various vision tools include a boolean value that tells you whether the tool found anything. This value should be checked before attempting to access any of the other data array values. This is particularly important during multiple iterations of the program. When a tool instruction is processed, the previously created array values are not deleted; they are overwritten with any new values generated. This means that if a tool fails, the only array value overwritten will be the one indicating that the tool failed. The other array values will contain the values from the previous iteration of the tool.

Location values should be checked to see if they can be reached by the motion device. It is possible to create a transformation that the motion device cannot reach. The INRANGE function can be used to check a location prior to issuing the move instruction to that location.

During the teaching phase of the program, the operator should have been given the opportunity to verify the locations. For critical locations, teaching the location several times and then averaging the components of each instance may be in order.

All I/O instructions should be checked with the IOSTAT function to make sure they were successful. Since I/O failures are not fatal, if your program does not detect and deal with them, the program will continue on as if the I/O were successful.

Generalizing the Program

The above program has several constraints that could be alleviated to make it more versatile. The first restriction is on the shape of the parts. The program assumes they are radially symmetrical so the robot gripper can pick them up in any orientation. If the parts are not radially symmetrical, the grip transformation would need to take into account any offset or rotation. The part pickup location would also need to have the rotational component calculated. One method of finding this orientation is with the major ellipse axis data available through VFEATURE. If the part has been prototyped, the prototype reference frame can be used to calculate the part rotation.

The pallet is allowed to move only parallel to the robot Y axis. This restriction could be removed by putting unique fiducial marks on the pallet and then using the vision system to calculate the pallet's orientation.

This example uses an "indexing" conveyor—the conveyor moves parts into position and then stops until the assembly or palletizing operation is complete. The *V⁺ Language User's Guide* provides details on setting up and calibrating a moving conveyor.

The inspection of the part was extremely simple. A realistic inspection would require additional tools and possibly presentation of the part to the camera in different orientations.

Advanced Operations 14

Performing High-Speed Inspections 250
- What is "High Speed"? 250
- Using the Two Frame Store Areas 251
- Using VPICTURE With Different Frame Stores 251
- Using VDISPLAY With Different Frame Stores 252
- Sample Code for a High-Speed Inspection 252
- The High-Speed Trigger 254

Performing Frame-Relative Inspections 255
- Blob-Relative Inspection 255
- Prototype-Relative Inspection 257

Frame-Relative Inspections Using VDEF.TRANS 258

Using a Vision-Guided Tracking Conveyor 260

Performing High-Speed Inspections

What is "High Speed"?

The definition of high speed will vary considerably from application to application. Generally, an operation that inspects parts on the order of several per second is considered a high-speed operation. The physical limit of AdeptVision VXL is one picture every 16 milliseconds. The actual rates you will be able to achieve depend on how complicated your inspections are, the level of operator feedback required, and the accuracy of positioning of the inspected parts.

You will achieve the highest inspection rates when you follow these guidelines:

1. Always acquire an unprocessed image (VPICTURE mode 2).
2. If you are displaying the image, display a frozen image. If you are displaying graphics, use the special mode described in the section below, "Using VDISPLAY With Different Frame Stores."
3. Enable V.BINARY so the edge operator is not performed at every picture.
4. Use both of AdeptVision VXL's frame stores to inspect alternating parts (the two frame stores are described next).
5. Have the system gather the minimum data required to successfully inspect the part.
6. Use vision tools, such as raw binary or fine-edge rulers, that operate on unprocessed image data whenever possible.
7. Rulers are faster when they are rotated exactly 0°, 45°, 90°, 135°, 180°, etc.
8. If an inspection needs to be performed on processed image data, perform the inspection within as small an inspection window as practical.
9. Make the inspection tools as small as practical.
10. VWINDOW, VWINDOWB, and VWINDOWI tools that are oriented orthogonally are much faster than rotated windows.
11. When using tools that return a variable number of elements to an array (such as VRULERI), limit the number of array elements the tool looks for.
12. On tools that allow you to set the effort level, set the lowest level possible that still achieves effective inspections.
13. Fixture the part as accurately as possible so processing time does not have to be expended looking for the part.
14. Organize the sequence of inspections so the most likely sources of failure are checked first. Terminate inspections as soon as a failure is detected.

15. A strobing device or a shuttered camera with a 1/1,000 shutter speed will be required for high-speed inspections.
16. Image processing and acquisition is faster with field acquires than with full frame acquires.
17. Make the object size only as large as necessary in the field of view so that required resolution is achieved.
18. Use low resolution virtual frame buffers whenever possible.

Using the Two Frame Store Areas

AdeptVision VXL provides you with two frame store areas into which you can store two different images. Each frame store area has two image buffers; raw grayscale data is stored in one buffer, and binary data is stored in the other. Using the two frame stores, you can acquire an image in one area while you are processing the image in the other area. This operation is referred to as "ping-ponging" (see **Figure 14-1**).

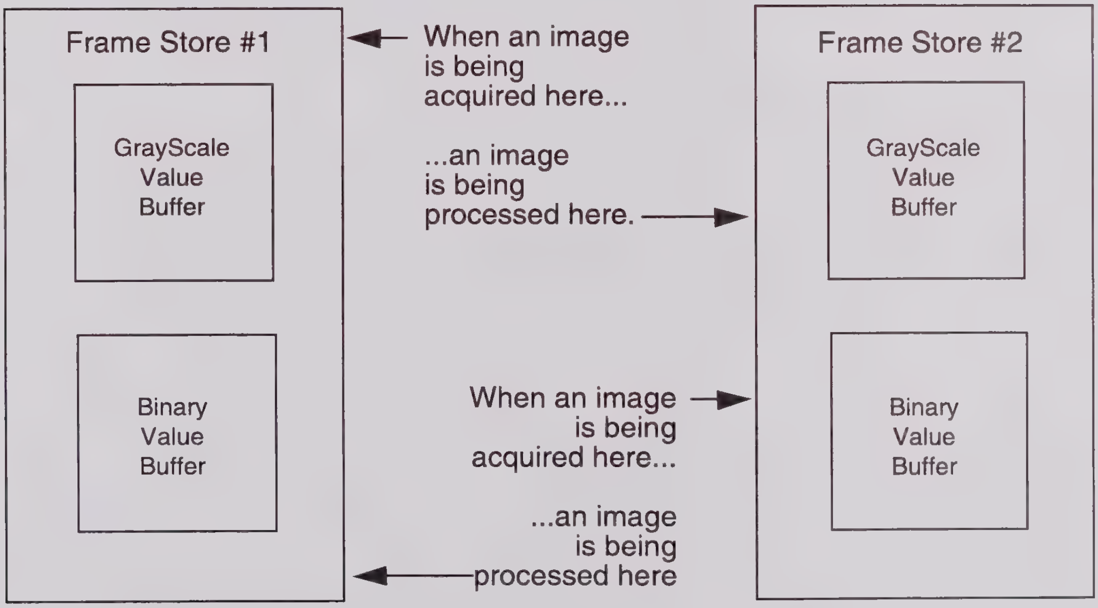

Frame Store #1
GrayScale Value Buffer
Binary Value Buffer
When an image is being acquired here...
...an image is being processed here.
When an image is being acquired here...
...an image is being processed here
Frame Store #2
GrayScale Value Buffer
Binary Value Buffer

Figure 14-1. Ping-Pong Frame Grabbing

Using VPICTURE With Different Frame Stores

In order to use both frame store areas, we will need to examine more of the VPICTURE syntax for a high-speed inspection:

VPICTURE(cam.virt, FALSE, acq_ibr, pro_ibr) 2

cam.virt	is the virtual camera number to be used.
acq_ibr	is the image buffer region into which the current picture will be acquired.
pro_ibr	is the image buffer region that subsequent processing is to take place on. The definitions of **acq_ibr** and **pro_ibr** must specify different physical frame stores.

Using VDISPLAY With Different Frame Stores

The VDISPLAY instruction has a special mode to be used when both frame stores are being used in a ping-pong fashion and you want to see system- or user-generated graphics. The problem with using a graphics overlay in ping-pong frame grabbing is that before the graphics can be adequately displayed, the system is acquiring another image and overwriting the existing graphics. Using the special mode (5) allows you to instruct one frame area to not display an image, thus allowing the other frame store exclusive access to the monitor. The next section shows how this special mode would be used in a high-speed application.

Sample Code for a High-Speed Inspection

Let's write the code shell for high-speed inspection of parts on a moving belt. An operator-generated input signal (1030) will control program execution. The program will signal belt motion with digital output signal 34. When the part is in place, a proximity switch will return digital input signal 1032.

```
; Declare local variables

    AUTO first.frm, second.frm, cam1, cam2, vfb1, vfb2, aoi
    AUTO do.belt, di.part_ready, di.begin

; Initialize variables

    cam1 = 1
    cam2 = 2
    vfb1 = 11;default area-of-interest, frame store 1
    vfb2 = 12;default area-of-interest, frame store 2
    aoi = 10000;area-of-interest 10
    do.belt = 34
    di.part_ready = 1032
    di.run = 1030

; Define the AOIs
```

```
   VDEF.AOI aoi = 1, 20, 20, 10, 5
   first.frm = aoi+vfb1;virtual frame buffer 11
   second.frm = aoi+vfb2;virtual frame buffer 12

; Set switches and parameters

   ENABLE V.BINARY
   ENABLE V.STROBE

; Set display mode to a grayscale frame store with graphics overlay
; and display only the image from camera 2

   VDISPLAY (cam1) 5
   VDISPLAY (cam2) 1, 1

; Wait for the ready signal and start the belt

   WAIT SIG(di.run)
   SIGNAL do.belt

; Wait for the first part to be ready and then acquire
; the first image in a wait mode so we insure an image is present
; when we begin processing during the second image acquisition

   DO
   UNTIL SIG(di.part_ready)
   VPICTURE (cam2, TRUE, second.frm, first.frm) 2

; Begin the ping-pong routine

   DO

; Start a busy loop waiting for part to be ready

       DO
       UNTIL SIG(di.part_ready)

; Acquire an image with camera 1 and select frame store 2 for processing

       VPICTURE (cam1, 0, first.frm, second.frm) 2

; Inspect the part

       VWINDOWB d2[] = second.frm
       ; Deal with results

; Wait for the next part

       DO
       UNTIL SIG(di.part_ready)

; Acquire an image with camera 2 and select frame store 1 for processing

       VPICTURE (cam2, 0, second.frm, first.frm) 2
```

```
; Inspect the part

        VWINDOWB d1[] = first.frm
        ; Deal with results

    UNTIL NOT SIG(di.run)

; Inspect the final part

    VWINDOWB d2[] = second.frm

; Deal with results
```

The actual time required for ping-pong inspection will be determined by the frame store requiring the longest processing time. If your inspection operations take 75 milliseconds and acquisition takes 33 milliseconds, processing on the newly acquired image will have to wait 42 milliseconds while processing finishes on the other image.

The High-Speed Trigger

In the above example, image acquisition is started when the part-present sensor signals that a part is ready. There is a small potential delay due to the way digital signals are monitored in V$^+$. Digital signals are read once every major CPU cycle. Thus, a slight delay may be encountered before the system actually registers the digital signal. To overcome this delay, a digital signal can be configured as an "external" trigger. When the state of an external trigger changes, a system interrupt is generated and the signal is registered immediately (within .02 ms).

Before you can use an external trigger, you must run the controller configuration utility CONFIG_C to specify the digital signal to monitor as an external trigger. See the *Instructions for Adept Utility Programs* and the description of V.IO.WAIT in the *AdeptVision Reference Guide*.

When you use a high-speed trigger, image acquisition becomes dependent on the state of the vision switch V.IO.WAIT. If V.IO.WAIT[cam] is set to 1, image acquisition by camera "cam" will wait until the state of the external trigger transitions before acquiring an image (the specific digital signal used for the external trigger does not have to be specified).

Performing Frame-Relative Inspections

In many applications, the object's being presented to the camera may be in random orientation. Frame-relative inspections allow you to orient inspection tools with respect to the object's actual orientation. In frame-relative inspections, a reference frame is generated based on an object's location in the field of view, and vision tools are placed relative to this reference frame rather than the vision reference frame. If you are inspecting a line of similar objects, or objects that are easily distinguished with vision tools, you would use finder and ruler tools or boundary analysis data to create the relative frame. If you are inspecting a line of multiple object types that need prototype identification before they are inspected, you would use prototype-relative inspection.

The programming example in Chapter 12 presented a simple example of using line finders to place frame-relative inspection tools. The main disadvantage of the strategy in the example program is that the object's location and rotation must be constrained. A more sophisticated strategy that removes this constraint is to create a reference frame for the object and then place inspection tools relative to the new reference frame. The following examples create reference frames based on an object's location, and then place inspection tools based on that reference frame.

Blob-Relative Inspection

When a blob is located, it will have a reference frame with the same orientation as the vision reference frame. The starting point of this reference frame is the centroid of the blob (see the V.CENTROID switch for additional details). If the blob has a strong elliptical character, you can identify the change in orientation based on the VFEATURE( ) data generated by a VLOCATE operation. Using the VFEATURE( ) data and the origin of the blob reference frame, you can create a reference frame unique to each found blob. Is that perfectly clear? Let's examine some sample code that places a blob-relative ruler:

```
; Initialize the ruler location variables. These variables represent the
; location of the ruler relative to the centroid and rotation of the blob.

    ruler_ang = 45;Angle of the ruler, relative to object's orientation
    xoffset = -8;x offset of the ruler start point
    yoffset = 0;y offset of the ruler start point
    length = 50;Length of the ruler
    cam = 1

; Enable gathering of centroid, perimeter, and min/max radii data
```

```
    ENABLE V.BOUNDARIES
    ENABLE V.CENTROID
    ENABLE V.PERIMETER
    ENABLE V.MIN.MAX.RADII

;Get the object's location variable with a VLOCATE instruction

    VPICTURE (cam)
    VWAIT
    VLOCATE (cam, 2) "?", obj_loc

; Calculate the object rotation based on the angle of a line from the blob center
; to the farthest point on the blob. The major ellipse axis is not used
; because the positive direction of the X axis is not known without further
; calculations.

    obj_rotation = VFEATURE(45)

; Rotate the reference frame by 'obj_rotation' and offset it by tool location
; offsets.

    SET tool_loc = obj_loc:RZ(obj_rotation):TRANS(xoffset,yoffset)

; Using the orientation and starting point of the blob, place the frame
; relative ruler

    VDEF.AOI 2000 = 2, DX(tool_loc), DY(tool_loc), length, 0,
                                                  ruler_ang+obj_rotation
    VRULERI (cam) ruler_data[] = 2000
```

Figure 14-2 shows how the reference frame for the preceding code was calculated.

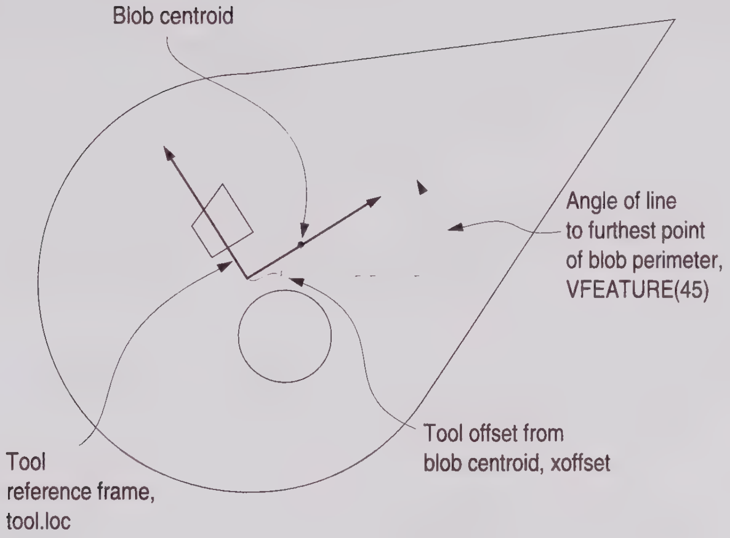

Blob centroid
Angle of line to furthest point of blob perimeter, VFEATURE(45)
Tool offset from blob centroid, xoffset
Tool reference frame, tool.loc

Figure 14-2. Blob-Relative Inspection

Prototype-Relative Inspection

If the objects you are inspecting:

- Are similar and cannot be identified by blob recognition or by using a combination of finder and ruler tools
- Do not have a strong elliptical character or other features that define the object's rotation
- Are touching or overlapping

then prototyping may be the best way to define a reference frame for the object.

Prototypes have their own reference frame based on the orientation of the part the first time it was trained. When a prototype is recognized (VLOCATE operation), a reference frame based on the recognized object is returned. The following code will place a prototype-relative ruler.

```
; Identify the offset and rotation of the tool relative to the prototype
;    reference frame.

    xoffset = -5          ;ruler x offset from proto reference frame
    yoffset = 30          ;ruler y             "
    ruler_ang = 320       ;ruler angle
    length = 50           ;ruler length (relative to proto ref frame)
    cam = 1
    ENABLE V.RECOGNITION;enable prototype recognition
    ENABLE V.CENTROID

; Acquire a processed image and locate the prototype.

    VPICTURE (cam)
    VLOCATE (cam, 2)"sample_object", proto.loc

; Create tool location variables based on the prototype reference frame.
;    The X and Y values of the origin of the prototype reference frame are
;    returned in VFEATURE(2) and VFEATURE(3).

    tool.x = VFEATURE(2)+xoffset
    tool.y = VFEATURE(3)+yoffset

; The rotation of the object relative to the prototype frame of
;    reference is contained in VFEATURE(7).Create a variable for this angle.

    obj_ang = VFEATURE(7)
    tool_ang = obj_ang+ruler_ang

; Issue a VRULERI instruction that uses the X and Y values from
;    the location variable for the center of the ruler, and adds
;    the object rotation to the angle of the ruler.

    VDEF.AOI 2000 = 1, tool.x, tool.y, length, tool_ang
    VRULERI (cam) data[] = 2000
```

Blob and prototype recognition are relatively processing-intensive and may be too slow for high-speed inspections. The location and position data returned from vision tools operating in binary mode or grayscale on an unprocessed image may provide you with a less processing-intensive way of creating object-relative reference frames.

Frame-Relative Inspections Using VDEF.TRANS

The VDEF.TRANS instruction will offset and rotate a defined AOI. The following code shows the use of the VDEF.TRANS function for part relative tool placement in inspection vision. In this example, the radius of the hole in a part is inspected.

```
; Declare local variables

    AUTO shape, xoffset, yoffset, outer.r, inner.r, cam, circ_ibr
    AUTO $name, data[10]

    shape = 9       ; donut-shaped AOI
    xoffset = -50  ; x-offset for center of arcfinder relative to part
    yoffset = -75  ; y-offset for center of arcfinder relative to part
    outer.r = 45   ; outer radius
    inner.r = 15   ; inner radius
    cam = 1
    circ_ibr = 2000

; Set switches and a parameters

    ENABLE V.BOUNDARIES
    ENABLE V.CENTROID
    ENABLE V.MIN.MAX.RADII

; Define AOIs

    VDEF.AOI circ_ibr = shape, xoffset, yoffset, outer.r, inner.r

; Locate the object using blob finding

    VPICTURE (cam)
    VWAIT
    VLOCATE (cam) $name

; Define a vision transformation with centroid and angle of max radius.

    VDEF.TRANS VFEATURE(42), VFEATURE(43), VFEATURE(45)

; Using the defined AOI which will now be part-relative, use an arc finder
;   placed over the hole to extract the hole data

    VFIND.ARC (cam) data[] = circ_ibr

; Type result for radius

    TYPE "Hole Radius = ", data[4]

; Zero the vision transformation

    VDEF.TRANS
    VDISPLAY (cam) 0, 1
```

Using a Vision-Guided Tracking Conveyor

An upstream, fixed-mount camera can be used to locate parts on a moving conveyor belt. The following basic steps must be taken to use vision with a moving conveyor:

- The conveyor must be mounted and calibrated to the robot (see the *V⁺ Language User's Guide*).
- The camera must be mounted upstream of the robot with a field of view that will encompass all the belt width that might have parts.
- The camera must be calibrated using the "object on moving belt..." option in the Advanced Camera Calibration program (see **Chapter 4**).
- See the *V⁺ Language User's Guide* for details on defining belt-relative locations.
- The part location must be taught dynamically with a program that contains the following six steps:

1. Prompts for a part to be placed upstream of the camera
2. Starts the calibrated conveyor moving
3. When the part enters the field of view, either stops the conveyor and allows the user to take a picture or relies on a digital signal to trigger the picture taking
4. Moves the conveyor until the part is in the robot's work envelope
5. Stops the conveyor and prompts the user to manually grip the part (without moving it)
6. Records the location relative to the belt location and the camera transformation

Switches and Parameters A

Setting Vision Switches 262
Viewing Switch Settings 262
Setting Vision Parameters 262
Viewing Parameters 263
List of Switches 263
List of Parameters 266

Setting Vision Switches

```
ENABLE switch[cam.virt],...,switch[cam.virt]
```

```
DISABLE switch[cam.virt],...,switch[cam.virt]
```

`switch`	is replaced with any of the switches listed in Table A-1.
`cam.virt`	is replaced with the number of the camera you want to set the switch for. The default value is *all* cameras. If you are using multiple cameras with different switch settings, make sure you include a camera number with each SWITCH command.

Viewing Switch Settings

To see the settings for all switches (for the virtual cameras specified by the system parameter DISPLAY.CAMERA), issue the command:

```
SWITCH
```

Setting Vision Parameters

```
PARAMETER parameter_name[cam.virt] = value
```

`parameter_name`	is replaced with the name of the parameter you want to set.
`cam.virt`	is replaced with the camera number you want to set the parameter for. The default is *all* cameras. If you are using multiple cameras with different parameter settings, make sure you include a camera number with each PARAMETER command.
`value`	is replaced with the new value you want the parameter to have.

Viewing Parameters

To output the parameter list to the screen, issue the command:

```
PARAMETER
```

List of Switches

This table lists all the switches available to AdeptVision VXL and a brief description of what they do. Complete information on each switch is available in the *AdeptVision Reference Guide.*

Table A-1. Vision Switches

Switch	**Default**	**Effects**
V.2ND.MOMENTS		The 2nd moments of inertia and best-fit ellipse are calculated when this switch is enabled (along with V.CENTROID and V.BOUNDARIES). The data is reported in VFEATURE(48-50). (V.SUBTRACT.HOLES is ignored.)
V.BACKLIGHT	✔	The system has no way of differentiating between background and object unless you tell it which one is dark and which one is light. This switch tells the system which intensity is background and which intensity is object. If the switch is set incorrectly, the system will process the background rather than the object. Disable the switch for a dark background and enable it for a light background. (Binary processing only.)
V.BINARY	✔	If disabled, it will affect the operation of VPICTURE modes –1, 1, and 2 in the following ways: For VPICTURE modes 2 and 1, it will start a VEDGE operation immediately following the completed acquisition into the virtual frame buffer. For VPICTURE mode –1, a VEDGE operation is performed prior to processing of the image. In this case, the VPICTURE instruction will not complete until after the first stage of processing (the computation of run-lengths) is complete. Therefore, the run-lengths are computed on the binary edge image which is the result of VEDGE (see Appendix B in the *AdeptVision Reference Guide* for details on how vision run-lengths are generated). In each case above, the choice of edge operation to be performed (cross-gradient or Sobel) is determined by the value of the system parameter V.EDGE.TYPE. The edge strength threshold is given by the V.EDGE.STRENGTH system parameter.

Table A-1. Vision Switches (Continued)

Switch	Default	Effects
V.BOUNDARIES	✓	Enables or disables boundary processing. If this switch is disabled, perimeter, edge, centroid, 2nd moments, and hole data will not be gathered. Must be enabled for vision model processing.
V.CENTROID		The centroid of an object is calculated if this switch is enabled. This information is then available in VFEATURE(42-43). This switch increases processing time and should be disabled if the centroid information is not needed. (V.BOUNDARIES must be enabled.)
V.DISJOINT	✓	A single object may appear to the vision system to be two separate objects. (E.g., a dark object with a white line down the middle would look like two objects.) If you are attempting prototype recognition on this type of part, this switch will have to be enabled or the part will not be recognized. Disable this switch when you are not doing prototype analysis. When doing region analysis, this switch must be disabled for hole data to be gathered.
V.DRY.RUN		Allows you to see the placement of vision tools without having the tools actually perform any processing. Useful during development when you are trying to position your tools. A graphics display mode must be selected.
V.EDGE.INFO		Enabling this switch causes the system to gather statistics about edges. These statistics will be available through the instruction VEDGE.INFO.
V.FIT.ARCS	✓	Enabling this switch causes the system not to attempt to fit arcs during boundary analysis. If arcs are unimportant in your application, processing time will be improved by disabling this switch.
V.HOLES		If this switch is enabled, the statistics gathered for objects will also be gathered for the holes in the objects. The total number of holes in a region is available in VFEATURE(40). After an individual hole has been VLOCATEd, all its features are available through VFEATURE.
V.MIN.MAX.RADII		The points closest to and farthest from the centroid of an object are calculated when this switch is enabled. The data is available in VFEATURE(44-47). (V.BOUNDARIES and V.CENTROID must be enabled.)
V.OVERLAPPING		Enabling V.OVERLAPPING will improve recognition of parts that are overlapping. This switch increases processing time for part recognition and should be disabled if objects do not overlap. (V.TOUCHING is assumed to be enabled whenever this switch is enabled.)
V.PERIMETER		The perimeter of an object is available in VFEATURE(41) if this switch is enabled.

Table A-1. Vision Switches (Continued)

Switch	**Default**	**Effects**
V.RECOGNITION	✓	Disabling this switch will cause the system to behave as if no prototypes have been defined. Must be enabled to perform prototype recognition.
V.SHOW.BOUNDS		If this switch is enabled, the vision system will display the results of fitting lines and arcs during boundary analysis. This switch is useful during development as it allows you to see how the vision processor performs boundary analysis. (All the "SHOW" switches require a graphics display mode or overlay.)
V.SHOW.EDGES		If this switch is enabled, the vision system will display the primitive edges fit to an object's boundary.
V.SHOW.FEATS		If this switch is enabled, the vision system will display the features used for ObjectFinder recognition. (This switch is similar to V.SHOW.BOUNDS. However, it applies to lines and arcs used in object finding, not blob or prototype finding.)
V.SHOW.GRIP	✓	If robot gripper positions have been defined for a prototype, enabling this switch causes the system to show the effects of clear-grip tests.
V.SHOW.RECOG	✓	If this switch is enabled and a part is recognized, the silhouette of the prototype model will be overlaid on the part.
V.SHOW.VERIFY		Enabling this switch will cause the system to display all attempts the system makes during prototype recognition. This switch is useful during development when you attempt to create prototypes that produce the most accurate results in the least amount of time. It should be disabled during normal operations.
V.STROBE		Whenever a VPICTURE instruction is issued and this switch is enabled, a strobe signal is sent to the strobe port of the camera taking the picture.
V.SUBTRACT.HOLE		When this switch is enabled, the area of holes within an object will be subtracted from the area calculation (reported in VQUEUE and VFEATURE(10). (See Appendix B for VFEATURE information.) This switch affects the performance of V.MIN.AREA, V.MAX.AREA, and V.MIN.HOLE.AREA.
V.TOUCHING		If the objects you are attempting to recognize are touching each other, the system will see them as one object and may fail to recognize multiple touching objects. If objects in the field of view touch, and you need to recognize all of them, enable this switch. This switch may increase processing time for part recognition. See the *AdeptVision Reference Guide* for details on how V.TOUCHING, V.DISJOINT, and V.OVERLAPPING interact.

Table A-1. Vision Switches (Continued)

Switch	Default	Effects
VISION	✓	Disabling this switch will cause the system to behave as if the vision option is not installed. When this switch is enabled from the monitor prompt (using the ENABLE VISION command), the vision hardware is reinitialized only (takes 1-2 seconds). Frame grabber testing is done only at system startup.

List of Parameters

This table lists all the parameters available to AdeptVision VXL and a brief description of what they do. Complete information on each parameter is available in the *AdeptVision Reference Guide.*

Table A-2. Vision Parameters

Parameter	Default	Range	Effects
DISPLAY.CAMERA	4	1 32	Sets the number of camera values that will be displayed when a PARAMETER or SWITCH command is issued.
V.2ND.THRESH	0	0 127	Used with V.THRESHOLD to establish a range of intensities that the system will see as black or white. With V.THRESHOLD at 50 and 2ND.THRESHOLD at 70, all pixels between 50 and 70 would be seen as dark.
V.BORDER.DIST	0*	0 100	Allows you to disable prototype recognition processing on objects that are not entirely within the field of view.
V.EDGE.STRENGTH	20	0 127	Sets the threshold at which the system recognizes an edge in grayscale processing. If the variation in pixel intensity in a local area exceeds this parameter, an edge is recognized.
V.EDGE.TYPE	1	1 2	A cross-gradient edge detector is used when this parameter is set to 1 and a Sobel edge detector is used when it is set to 2.

* Measurements are in pixels

Table A-2. Vision Parameters (Continued)

Parameter	**Default**	**Range**	**Effects**
V.FIRST.COL	1*	1 640	Sets the first column that will be processed by a VPICTURE or VWINDOW instruction. Used to speed processing time by ignoring unwanted areas of the left side of the field of view. Must be less than V.LAST.COL.
V.FIRST.LINE	1*	1 480	Sets the first line that will be processed by a VPICTURE or VWINDOW instruction. Used to speed processing time by ignoring unwanted areas at the bottom of the field of view. Must be less than V.LAST.LINE.
V.GAIN	128	1 256	AdeptVision VXL recognizes 128 degrees of intensity. V.GAIN works with V.OFFSET to maximize the use of these 128 values.
V.IO.WAIT	0	0 1	When this parameter is set to 1, image acquisition will wait until the digital input channel configured as an external trigger transitions.
V.LAST.COL	640*	1 640	Sets the last column that will be processed. Everything to the right of this column will remain unprocessed. Must be greater than or equal to V.FIRST.COL.
V.LAST.LINE	480*	1 480	Sets the last line that will be processed. Everything above this line will remain unprocessed. Must be less than or equal to V.FIRST.LINE.
V.LAST.VER.DIST	0*	0 16	Sets the degree of accuracy for boundary-to-prototype model fitting required when a successfully recognized prototype is reverified. When this switch is set to 0, the additional verification process is defeated.
V.MAX.AREA	307,200*	1 1,048,576	Sets a value for the largest object the system will attempt to process. Useful if a large object is in the same field of view as the object you are interested in. The setting V.SUBTRACT.HOLES affects this parameter. Must be greater than or equal to V.MIN.AREA.
V.MAX.PIXEL.VAR	1.5*	0 8	Sets the maximum pixel variation allowed when the system fits a line or an arc to a region. When set to 0, lines and arcs are not fit to the boundary, saving time when only centroids, perimeters, etc., are needed.
V.MAX.TIME	5	1 999	Sets the maximum time the vision system will spend trying to recognize a region.

* Measurements are in pixels

Table A-2. Vision Parameters (Continued)

Parameter	**Default**	**Range**	**Effects**
V.MAX.VER.DIST	3*	1 16	Sets the degree of accuracy of boundary-to-prototype model fitting required for a successful prototype recognition.
V.MIN.AREA	16*	1 1,048,576	Sets a value for the smallest object the system will attempt to process. Useful for ignoring small objects you are not interested in and for filtering noise. The setting of V.SUBTRACT.HOLES is considered when comparing area values. Must be greater than or equal to V.MIN.HOLE.AREA and less than or equal to V.MAX.AREA.
V.MIN.HOLE.AREA	8*	1 1,048,576	Sets a value for the smallest hole in an object that the system will process. The setting of V.SUBTRACT.HOLES is considered when comparing area values. Must be smaller than or equal to V.MIN.AREA.
V.MIN.LEN	40	0 No max	Sets a value for the minimum length of features to be used for pairs. This parameter is used by VTRAIN.FINDER and VPLAN.FINDER (see those program instructions in the *AdeptVision Reference Guide* for details).
V.OFFSET	255	0 255	AdeptVision VXL recognizes 128 degrees of intensity. V.GAIN works with V.OFFSET to maximize the use of these 128 values.
V.THRESHOLD	63	0 127	Sets the intensity at which the system sees a pixel as either black or white.

* Measurements are in pixels

VFEATURE( ) Values B

Viewing VFEATURE( ) Values 270
Establishing VFEATURE( ) Values 270

Viewing VFEATURE( ) Values

VFEATURE( ) is not a monitor command or a program instruction. It is a system function that returns a value. As such, it can be used in most places you would use a variable. For example:

```
IF VFEATURE(10) > 975 THEN...
```

or

```
part_centerx = VFEATURE(42)
```

(A critical point to remember when using VFEATURE is that it is a function that returns a value and not an array of values. You cannot assign a value to a VFEATURE( ) index. For example, the instruction:

```
VFEATURE(12) = 3.303
```

would not be accepted by the V+ system.)

Establishing VFEATURE( ) Values

VFEATURE( ) values are established as the result of a successful VLOCATE or VSHOW instruction. You cannot directly view or set these values. Before attempting any access to a VFEATURE( ) value, your program should contain an instruction to check the success of the last VLOCATE or VSHOW instruction. Here is an example:

```
IF VFEATURE(1) THEN
    ;{strategy when object found}
ELSE
    ;{strategy when no object found}
END
```

Tables B-1 and B-2 provide information about prototype recognition instances (following VLOCATE and VSHOW). Tables B-3 and B-4 provide information about ObjectFinder models (following VLOCATE and VSHOW).

Table B-1. VFEATURE( ) Values and Interpretation for Prototype Recognition Instances (following VLOCATE)

Index	Information	Unit	Switch/Parameter Effects
1	Whether the last VLOCATE instruction was successful or not	T/F	As long as a VLOCATE operation successfully removes objects from the vision queue, this value will be returned as true (–1) and information about that object will be available through VFEATURE access.
2	Center X	mm	After a VLOCATE: With V.CENTROID enabled, the location components are the centroid of the region. With V.CENTROID disabled, the location components are the center of the bounding box of the region. The reference frame is relative to the vision reference frame.
3	Center Y		
4	Center Z		
5	Rotation about X	°	
6	Rotation about Y		
7	Rotation about Z		
8	Encoder offset	See the *V^+ Language User's Guide*	
9	Percentage of boundary that matched during prototype recognition (will be 0 for unrecognized regions)	%	After VLOCATE: % of prototype verified.
10	Area of object	raw pixels	If V.SUBTRACT.HOLES is enabled, the area of holes in the object is subtracted from this calculation. Note that this is the area of the region, not the area of the prototype.
11	ID numbers	#	V.DISJOINT, V.TOUCHING, and V.OVERLAPPING will influence the number of objects processed.
12			
13	Left limit of region bounding box	mm	After VLOCATE: Bounding box is relative to vision reference frame.
14	Right limit of region bounding box		
15	Lower limit of region bounding box		
16	Upper limit of region bounding box		
17	Number of holes in the region	#	V.HOLES must be enabled.

Table B-1. VFEATURE( ) Values and Interpretation for Prototype Recognition Instances (following VLOCATE) (Continued)

Index	Information	Unit	Switch/Parameter Effects
18	Time	secs	Time spent acquiring, processing, and recognizing an object. Time for first region includes all time from V.PICTURE (or VWINDOW) until placing in queue. For remaining regions, time is from when one region is placed in the queue until the next object is queued.
19	Flags	bit	Bit field (True/False). Bit 2 - Defined when V.HOLES is enabled. Indicates that the region VLOCATEd helped to verify the recognition of the object. All other bits are reserved for future use.
20	First clear grip		Returns number of first clear grip if grips have been defined with V.DEF.GRIP.
21	When an object is located, all the holes within the object are given a reference number. This value is the reference number of the current hole. (Also holds true for "holes within holes.")	#	Holes can be located within a bounded region or within a hole in a bounded region. These values keep track of where you are in the locating sequence. Holes are numbered consecutively for each region.
22	Parent number of holes referenced in VFEATURE(21)	#	
23	Number of the virtual camera that located this object	#	
24 - 26	Not used		
27	Number of bounds in the prototype or region	#	In prototypes, holes are included. In regions, they are not.
28 - 39	Not used		
40	Total area of all holes	pixels	Calculation is influenced by V.MIN.HOLE.AREA.
41	Outer perimeter of the object	mm	V.PERIMETER must be enabled.
42	Object centroid along X axis	mm	V.CENTROID must be enabled. V.SUBTRACT.HOLES is ignored.
43	Object centroid along Y axis		
44	The angle (relative to the object's centroid) of a line drawn to the closest point on the object perimeter	°	V.CENTROID and V.MIN.MAX.RADII must be enabled.

Table B-1. VFEATURE( ) Values and Interpretation for Prototype Recognition Instances (following VLOCATE) (Continued)

Index	Information	Unit	Switch/Parameter Effects
48	The direction of the object's major axis. The ellipse is centered at the region's centroid (axis of least inertia). This is the major axis of the best-fit ellipse.	°	V.CENTROID and V.2ND.MOMENTS must be enabled.
49	Major radius of the ellipse defined in VFEATURE(48)	mm	
50	Minor radius of the ellipse defined in V.FEATURE(48)		

Table B-2. VFEATURE( ) Values and Interpretation for Prototype Recognition Instances (following VSHOW)

Index	Information	Unit	Switch/Parameter Effects
1	Whether the last VSHOW instruction was successful or not	T/F	As long as a VSHOW operation successfully displays a prototype, this value will be returned as true (–1) and information about that object will be available through VFEATURE access.
2	Center X	mm	After a VSHOW: The location components are the prototype's centroid. The reference frame values are the prototype's reference frame.
3	Center Y		
4	Center Z		
5	Rotation about X	°	
6	Rotation about Y		
7	Rotation about Z		
8	Encoder offset	See the V^+ *Language User's Guide*	
9	Percentage of boundary that matched during prototype recognition	%	After VSHOW: recognition % specified during training.
10	Area of object	raw pixels	If V.SUBTRACT.HOLES is enabled, the area of holes in the object is subtracted from this calculation. Note that this is the area of the prototype, not the area of the region.
11	ID numbers	#	V.DISJOINT, V.TOUCHING, and V.OVERLAPPING will influence the number of objects processed.
12			

Table B-2. VFEATURE( ) Values and Interpretation for Prototype Recognition Instances (following VSHOW) (Continued)

Index	Information	Unit	Switch/Parameter Effects
13	Left limit of prototype bounding box	mm	After VSHOW: Bounding box is relative to prototype reference frame.
14	Right limit of prototype bounding box		
15	Lower limit of prototype bounding box		
16	Upper limit of prototype bounding box		
17	Number of holes in the prototype	#	V.HOLES must be enabled.
18	Time	secs	Time spent acquiring, processing, and recognizing an object. Time for first region includes all time from V.PICTURE (or VWINDOW) until placing in queue. For remaining regions, time is from when one region is placed in the queue until the next object is queued.
19	Flags	bit	Bit field (True/False). Bit 2 - Used only for VLOCATE All other bits are reserved for future use.
20	Not used		
21	When an object is located, all the holes within the object are given a reference number. This value is the reference number of the current hole. (Also holds true for "holes within holes.")	#	Holes can be located within a bounded region or within a hole in a bounded region. These values keep track of where you are in the locating sequence. Holes are numbered consecutively for each region.
22	Parent number of holes referenced in VFEATURE(21)	#	
23	Number of the virtual camera that located this prototype	#	
24	Effort level assigned during training for prototype recognition, 1 to 4		Prototype must have been recognized. After VSHOW only.
25	Color of prototype when trained; 0 = black, 1 = white		
26	Number of samples taught during prototype training	#	
27	Number of bounds in the prototype or region	#	In prototypes, holes are included. In regions, they are not.

Table B-2. VFEATURE( ) Values and Interpretation for Prototype Recognition Instances (following VSHOW) (Continued)

Index	**Information**	**Unit**	**Switch/Parameter Effects**
28	Maximum area assigned to a prototype during training	pixels	After VSHOW only.
29	Minimum area assigned to a prototype during training		
30 31	Indicates the virtual cameras associated with the prototype	bit field	Bit field indicating the virtual cameras associated with a prototype. After VSHOW only.
32 33	Indicates the range of edge numbers for a prototype	#	After VSHOW only.
34	x constraint of prototype	mm	After VSHOW only. (Prototype parameters defined during prototype training)
35	y constraint of prototype		
36	angular constraint of prototype		
37- 50	Not currently used		

Table B-3. VFEATURE( ) Values and Interpretation for ObjectFinder Recognition Instances (following VLOCATE)

Index	**Information**	**Unit**	**Switch/Parameter Effects**
1	Whether the last VLOCATE instruction was successful or not	T/F	As long as a VLOCATE operation successfully removes objects from the vision queue, this value will be returned as true (–1) and information about that object will be available through VFEATURE access.
2	Center X	mm	After a VLOCATE: X and Y are the center of the bounding box of the instance relative to the image and rZ is the orientation relative to the X axis. If the instance has the same orientation as the model, then the same orientation as the model is returned. (The orientation of the models and instances are both relative to the X axis. The orientation of an instance is not relative to the orienation of the model.)
3	Center Y		
4	Center Z		
5	Rotation about X	°	
6	Rotation about Y		
7	Rotation about Z		
8	Encoder offset	See the V^{+} *Language User's Guide*	

Table B-3. VFEATURE( ) Values and Interpretation for ObjectFinder Recognition Instances (following VLOCATE) (Continued)

Index	Information	Unit	Switch/Parameter Effects
9	Percentage of boundary that matched during prototype recognition (will be 0 for unrecognized regions)	%	After VLOCATE: % of model verified.
11	Model number	#	In planning list, 1 through 10.
12	Instance ID	#	
13	Left limit of region bounding box	mm	After VLOCATE: Bounding box is relative to vision reference frame.
14	Right limit of region bounding box		
15	Lower limit of region bounding box		
16	Upper limit of region bounding box		
18	Time	secs	Time spent acquiring, processing, and recognizing an object. Time for first region includes all time from VWINDOW until placing in queue. For remaining regions, time is from when one region is placed in the queue until the next object is queued.
23	Number of the virtual camera that located this object	#	Virtual camera number 1 through 32
27	Number of features in the model	#	All of the line segments and circular arcs in the model are counted even if the weight (after multi-instance training) is zero.

Table B-4. VFEATURE( ) Values and Interpretation for ObjectFinder Models (following VSHOW)

Index	Information	Unit	Switch/Parameter Effects
1	Whether the last VLOCATE instruction was successful or not	T/F	As long as a VSHOW operation successfully displays a model, this value will be returned as true (–1) and information about that model will be available through VFEATURE access.

Table B-4. VFEATURE( ) Values and Interpretation for ObjectFinder Models (following VSHOW) (Continued)

Index	**Information**	**Unit**	**Switch/Parameter Effects**
2	X	mm	After a VSHOW: X and Y are the center and rZ is the orientation of the bounding box of the first training instance of the model. The position and orientation of the model is not changed by training additional samples. Note that Z, rX, and rY are not used.
3	Y		
4	Z		
5	Rotation about X	°	
6	Rotation about Y		
7	Rotation about Z		
9	Percentage of boundary that matched during prototype recognition (will be 0 for unrecognized regions)	%	After VSHOW: recognition % specified during training.
12	Minimum verify percentage	%	Result of multi-instance training. To be used as a recommendation in selecting verify percent on training page.
13	Left limit of region bounding box (Min_X)	mm	After VSHOW: Bounding box is relative to prototype reference frame.
14	Right limit of region bounding box (Max_X)		
15	Lower limit of region bounding box (Min_Y)		
16	Upper limit of region bounding box (Max_Y)		
17	Number of pairs	#	
19	Average verify percentage	%	Result of multi-instance training. To be used as a recommendation in selecting verify percent on training page.
20	Maximum verify percentage	%	Result of multi-instance training. To be used as a recommendation in selecting verify percent on training page.
21	Hierarchical level	#	The image processing level (0 - 2). See VTRAIN.FINDER in the *AdeptVision Reference Guide* for details.
22	Parent number	#	This value is always –1
23	Number of the virtual camera that located this object	#	Virtual camera 1 through 32
24	Effort level assigned during training for prototype recognition, 1 to 4	#	After VSHOW only. This value is always 0.

Table B-4. VFEATURE( ) Values and Interpretation for ObjectFinder Models (following VSHOW) (Continued)

Index	**Information**	**Unit**	**Switch/Parameter Effects**
25	Convergence measure	#	A measure of the convergence of the feature weights during multi-instance training. A higher value means the model is stabilizing (should be at least 3, but 2 may be acceptable in some situations).
26	Number of samples taught during model training	#	
27	Number of features in the model	#	All of the line segments and circular arcs in the model are counted, even if the weight (after multi-instance training) is zero.
28	Maximum pixel variation	#	(Units of pixels.) Controls the initial rough fitting of features to edges.
29	Maximum location distance	#	(Units of pixels.) Controls the distance between proposals to prevent too many proposals from being made in the same location.
30	Indicates the virtual cameras associated with the prototype	bit field	Bit field indicating the virtual cameras associated with a model (1 through 16)
31	Indicates the virtual cameras associated with the prototype	bit field	Bit field indicating the virtual cameras associated with a model (17 through 32)
32	Indicates the range of edge numbers for a prototype	#	First edge number (1)
33	Indicates the range of edge numbers for a prototype	#	Last edge number
34	x.constraint	mm	Not currently used, 0
35	y.constraint	mm	Not currently used, 0
36	ang.constraint	o	Not currently used, 0

ObjectFinder Primer C

Introduction 280

Object Recognition 280

- Feature Processing 280
- Step 1: Hypothesis Generation 281
  - Feature Classes 281
  - Proposals 281
  - Seeds 281
- Step 2: Confirmation 281
- Step 3: Refinement 282
- Step 4: Verification 282
  - Max Verify Dist and Verify Percent 282

Introduction

The ObjectFinder is a vision tool that recognizes objects and determines the object pose in the scene automatically, without requiring the user to figure out how to combine other tools to do the job. The object position and orientation returned by the ObjectFinder can be used to position other tools for inspection, or passed to a robot for picking the part.

The ObjectFinder uses a "generate and test" paradigm to match object models to sets of features (object instances) in the image. There are three stages in the use of the ObjectFinder: model training, planning, and recognition.

- Model training acquires a model for a part. The model is the set of features derived from the image of the part.
- Planning takes one or more part models and forms feature classes from the features of all models that have been selected for recognition.
- Recognition takes the features derived from an image and matches image features to model features. A reasonably complete one-to-one match of image features to model features constitutes the recognition of the part.

Training and planning are offline activities, while recognition is performed online. Since it is easier to understand the operations of training and planning by seeing how they affect recognition, the explanation of these activities is combined into the description of object recognition in the following section.

Object Recognition

Object recognition is divided into four steps: hypothesis generation, confirmation, refinement, and verification. These steps are preceded by a feature processing step for estimating features from the image.

Feature Processing

Feature processing involves detecting object edges and fitting line segments (polylines) and circular arcs to the edges. Line segments are fit to edges up to a corner, then a new line segment is started. Circular arcs are fit to sequences of line segments that approximate an arc.

The image features (line segments and circular arcs) are combined in various ways to form the features that are used for matching. These feature combinations are called pairs since they usually result from the combination of two image features. The same image processing operations are performed during both training and recognition, except that more passes of filtering are done during training to improve the features that are incorporated into the object model(s). More sophisticated filtering is used only during training, since training is not time-critical.

Step 1: Hypothesis Generation

Feature Classes

The pairs that are produced by the image processing step are collated into *feature classes* defined by the planning stage. The feature classes are combinations of features that are similar to the combinations of features found in the object model(s) after planning.

Proposals

A combination of image features—with specific characteristics that are likely to correspond to a special location on the object model—provides a hypothesis on the position and orientation of that object in the image. Hypotheses are called *proposals*, since the combination of features proposes a sequence of tests that result in either the verification of the presence of the object in the image at the particular position and orientation, or the rejection of the match.

Seeds

The initial feature combination that produced the proposal is called a *seed*, since it determines an initial placement of the model in the image, and the search tree grows from that initial match. Any combination of image features that does not fall into at least one feature class is discarded, since that feature combination does not occur in any model and will not generate proposals. The feature class is ordered so that the classes that contain the highest number of seed pairs most likely to generate good hypotheses are considered first.

Step 2: Confirmation

Hypothesis generation leads to some false proposals, since a seed feature may not be matched to the correct model feature in all cases. For example, parts might have several right-angle corners, and each corner detected in an image may have to be matched against several model corners before the correct match is found. Each hypothesis must be verified (see **Step 4: Verification**) before the match is considered correct. However, verification is expensive, so confirmation attempts to prequalify the proposal by examining several additional potential matches between combinations of image and model features that are easy to find.

Step 3: Refinement

The matched pairs of image features and model features are used to refine the estimate of the position and orientation of the object instance in the image. This produces a better estimate of the transformation from model to image and reduces the chance of false positives (nonmatches that are perceived as matches) and false negatives (matches that are perceived as nonmatches) during verification.

Step 4: Verification

Finally, the proposed match is verified. Corresponding features are matched along some portion of their length, not just at particular points. Until this step, all of the processing has been done with pairs, which are points that have been derived from combinations of curve features. Now the actual line segments and circular arcs are considered.

Max Verify Dist and Verify Percent

The distance between points on the model curves and the corresponding points along the image curves must be within **max verify dist**. The portion of the corresponding curves that is within **max verify dist** is multiplied by the weight associated with the feature during training. The weighted sum for the verified portion of all model curves is computed and divided by the theoretical maximum, which is the weighted sum of the arc lengths of all the features in the model. This ratio is rounded down to the nearest integer and reported as the **verify percent** for the model instance.

Lens Selection D

Introduction 284
Formula for Focal Length 284
Formula for Resolution 286

Introduction

The following formulas are useful for selecting a camera lens. The optimum lens focal length depends on the desired measurement resolution, the width or height of the camera field of view, and the distance from the work surface to the camera.

Figure D-1 shows how an image is produced on the imaging element of the camera. A relationship exists between the camera-to-object distance, the size of the field of view, and the lens focal length. The size of the camera imaging element determines a scaling factor to be applied to this relationship. The relationship is given in the following formula.

Formula for Focal Length

The formula for focal length is:

$$f = S(C \div H)$$

where:

f = lens focal length in millimeters

S = camera scale factor (see **Table D-1**)

C = camera height (distance from front of lens to work surface)

H = height of camera field of view (same units as C)

Figure D-2 illustrates these relationships and the meaning of the camera scale factor. In the two examples in this illustration, the field-of-view width and the camera-to-object distance remain constant while two cameras with different size imaging surfaces are used. In order to keep the image within the imaging surface on both cameras, different focal length lenses must be used. By applying the correct camera scale factor for each camera (based on the imaging surface size), the correct lens focal length can be determined.

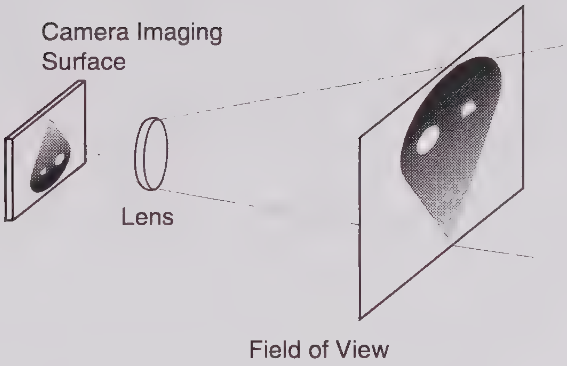
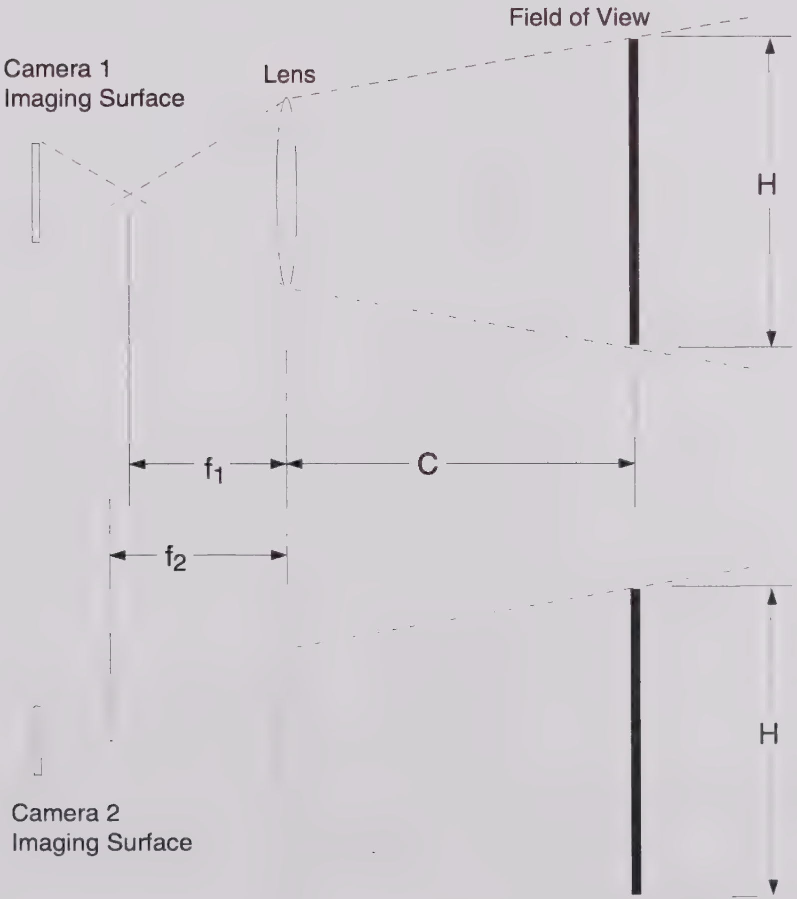

Camera Imaging Surface
Lens
Field of View

Figure D-1. Camera Imaging


Field of View
Camera 1 Imaging Surface
Lens
H
f_1
C
f_2
H
Camera 2 Imaging Surface

$f = S(C \div W)$

Figure D-2. Camera Scale Factor

The following formula shows the relationship between resolution and image size for AdeptVision systems.

Formula for Resolution

The formula for resolution is:

$$r = (H \div 480)$$

where:

r = resolution (height of one pixel)

H = height of field of view (same units as r)

Table D-1. Camera Scale Factors

Camera	**Scale Factor**
Panasonic GP-CD 40	4.8
Panasonic GP-MF 702	6.6
Sony XC-77	6.6

When choosing the size of the field of view, there is always a trade-off between image size and image resolution. When the image is large, more objects or features can be captured in each picture, which reduces the number of pictures required for the application. However, image resolution is reduced as the image size is increased, and resolution is the key to accurately locating and measuring image features. On the other hand, processing time increases as larger areas of the image are processed.

The following steps will help you decide on a lens and camera-to-object distance:

1. Determine the minimum required resolution (smallest feature that must be resolved accurately). We recommend that a factor of 5 to 10 be applied to this minimum resolution to guarantee consistent results.[1]

---

[1] This factor is sometimes referred to as the Part Tolerance Measurement Ratio (PTMR).

2. Based on the required resolution, determine the maximum field of view size. If the maximum available field of view is too small to view the entire object you are inspecting, you will have to:
   a. Use more than one camera to make the inspection.
   b. Move different areas of the part into the field of view and make multiple inspections.
   c. Accept a lower minimum resolution.
3. Using the upper and lower limits of the camera-to-object distances, determine the range of possible lenses.

For example, suppose you are using a medium-resolution camera. Your measurement accuracy needs to be within 0.1 mm, and the camera can be mounted 60 to 100 mm away from the object.

1. Using 1/4 pixel accuracy, apply a factor of 10 to the desired resolution and calculate the available field-of-view height:

$$r = (0.1 \div 10)(4)(480) = 9.2$$

2. Calculate the lens focal length at the minimum distance:

$$f = 4.8(60 \div 19.2) = 15$$

3. Calculate the lens focal length at the maximum distance:

$$f = 4.8(100 \div 19.2) = 25$$

4. Your application will achieve the desired resolution using lenses with focal lengths between 15 and 25 mm. If a 16 mm lens is selected, the proper viewing distance is:

$$16 = 4.8(C \div 19.2)$$

$$C = (16 \div 4.8)19.2 = 64$$

NOTE: The effective focal length of a given lens can be lengthened by adding extension tubes. However, extension tubes may introduce image distortion.

These calculations do not take into account any error introduced by manufacturing inaccuracies in the camera. In general, higher resolution cameras are better constructed and should be used when resolution tolerances are tight.

Lighting Considerations

E

Types of Lighting 290
Lighting Strategies 290
  Diffuse 290
  Back 291
  Directional 291
  Structured 291
  Strobe 291
Filtering and Special Effects 292
  Polarizing Filters 292
  Color Filters 292

Types of Lighting

Table E-1. Types of Lighting

Type	Advantages	Disadvantages
Incandescent	Inexpensive, can be cycled	Short life (for AC lamps), heat, inconsistent lumen output as wattage degrades
Fluorescent	Efficient, cool, large areas, low cost	Can not be cycled, flickers, not high intensity, large in size
Tungsten-Halogen	High output, compact	Heat
Strobes	High power, freezes motion	Expensive, lumen output may not be repeatable, must be synchronized with camera, potential health hazards
Lasers	Bright points and lines	Federally regulated, speckles, fragile, potential eye hazards
Laser diodes	Bright points and lines, small, can be easily pulsed, rugged	Federally regulated, requires collection optics, potential eye hazards

Lighting Strategies

Light is reflected from a surface at the opposite angle it struck the surface. Making use of this principle, lighting strategies employ the various properties of light sources and reflective materials to maximize important image detail, minimize unimportant details, and eliminate noise.

Diffuse

Diffuse lighting illuminates a surface with light that strikes the surface from as many different angles as possible, thus minimizing shadows, reflections, and the need for critically placed light sources.

Fluorescent lighting is the most diffuse of the lighting types listed in **Table E-1**. Diffuser plates and reflecting panels produce a more diffuse light. True diffuse lighting requires a parabolic reflector.

Applications with high-contrast, complicated objects, spherical objects, highly reflective objects, or objects that require multiple inspections of interior features are candidates for diffuse lighting.

Back

In backlighting, the light source (usually a diffuse source) is placed behind the object to be inspected.

Backlighting will effectively light objects whose silhouettes are the critical feature. This is particularly effective if the objects are highly reflective or have highly variable surfaces.

Directional

Incandescent floods, ring lights, and fiber lights mounted above or to the side of an object provide directional lighting.

This lighting is the simplest to install, but effective vision operations depend on this type of light source remaining constant. If the light source dims, the object will appear different to the camera. If the angle changes, shadows may be added that will be interpreted as features of the object.

This type of lighting will be most effective with simple objects or objects where specific, highly identifiable features are being inspected. Highly reflective surfaces or objects with variable surface brightness will be difficult to inspect with this type of lighting.

Structured

In structured lighting, a highly collimated light source is applied to the object. The angle of the light is coincident with camera axis. Ring lights and lasers are sources of collimated light.

This type of lighting allows the vision system to perceive three-dimensional features, such as depth changes in the surface plane or holes in the object. Reflective surfaces are not amenable to structured lighting.

Strobe

Strobe lighting is required in high-speed applications (multiple images per second) or when the speed of moving objects exceeds one pixel every 17 milliseconds.

Strobes cast harsh shadows.

Filtering and Special Effects

In many cases specific lighting problems can be solved by placing an optical filter on the camera lens. The two most common filters used for black and white cameras are polarizing filters and color filters.

Polarizing Filters

Reflected light is highly polarized (the light waves have a predominate orientation about the wave axis). A polarizing filter can be adjusted so that light waves with a predominate orientation are filtered. If reflected glare from an object is a problem, a polarizing filter may minimize the problem. A polarizing filter will reduce the overall scene brightness so more intense lighting sources will be needed with this type of filter.

By adjusting the orientation of polarizing filters on both the light source and lens, you can significantly reduce ambient light and reduce shiny (specular) reflections.

Color Filters

Color filters allow you to reduce or eliminate different colors of light that reach the camera. Color filters may enable the system to ignore annoying object features that are a given color, or ignore nonsignificant differences in an object that develop due to differences in the colors of the feature.

Color filtration is difficult and should be attempted only when other avenues have been exhausted.

F

Calibrating With HPS Data

Introduction 294
Using HPS Data 294

Introduction

If you have the Adept High-Accuracy Positioning System (HPS) option, data from that system can be used with the Advanced Camera Calibration Program while calibrating and testing the camera-to-robot relationship. (Refer to the manual for the HPS option for complete details on that system.)

This appendix addresses some considerations that should be kept in mind when using HPS data with the calibration program and with application programs.

Using HPS Data

Use of HPS data during camera calibration generally improves the accuracy of the calibration results. Thus, if HPS data is available, it should be used for any application with critical accuracy requirements.

For *stationary* cameras, if HPS data was used while calibrating an associated virtual camera, the same HPS data must also be used when the calibration results are used, including when the calibration results are tested with the calibration program. Likewise, if HPS data was *not* used during calibration, HPS data must *not* be used when the calibration results are used. When using a *stationary* camera, significant inaccuracies could result if HPS data is not used consistently.

For cameras *mounted on the robot*, use of HPS data during calibration will improve the calibration results. However, unlike the constraints mentioned above for stationary cameras, when using a camera mounted on the robot, HPS data does not need to be used during the application if it was used during calibration. Also, when the camera is mounted on the robot it is okay to use HPS data during the application even if the data was not used during the calibration procedure. Of course, using HPS data whenever possible results in improved accuracy.

The Advanced Camera Calibration program can make use of multiple HPS maps. This is needed when using the robot in both left-handed and right-handed configurations over the same work area, or when separate maps are needed for different calibrations around the workspace. When HPS maps are loaded into memory from disk by the program, the maps will be numbered consecutively starting with number 1.

If you are using HPS maps that were loaded previously, this numbering convention must have been followed. Otherwise, you must reload the maps using the Advanced Camera Calibration program.

If you are using HPS data with the "Link-2 noncontact (lefty/righty)" method, you *must* load at least one HPS map for each configuration.

If multiple HPS maps are to be used for any one camera calibration, those maps must be made using the same corner of the same HPS calibration plate, preferably during the same HPS mapping session. It is very important that the calibration plate *not* be moved between recording of the different HPS maps. However, it is okay if the configuration of the robot changes from one map to the next (for example, from right-handed to left-handed).

When an application uses a *stationary* camera with an HPS-based calibration, the rules in the previous paragraph apply. The *same* HPS maps used during calibration must be used for the application. The application can use the opposite robot configuration from that used during the camera calibration process, as long as the HPS map for the configuration is loaded into memory (following the restrictions mentioned above). That is, for example, camera calibration can be performed with the robot in a right-handed configuration, and the application can use the left-handed robot configuration if the corresponding "left-handed" HPS map is in memory while the application is running.

The HPS mappings provide a means to accurately position the center (of rotation) of the robot quill in an X-Y plane of the robot workspace. The HPS mappings will not be so helpful, however, if the pointer, vacuum gripper, or camera is mounted such that it is affected by the rotation of robot joint #4 (or #5). The positions of the center of the quill will still be accurate, of course, but the actual positions of the pointer, gripper, or camera will be limited by the accuracy of joint 4 (or 5). This effect, although small, is compounded by how far the pointer, gripper, or camera is from the center of the quill. Therefore, the accuracy improvement from the use of HPS data can be somewhat reduced when using an off-center pointer or gripper, or a camera mounted on link #4. This comment is valid only for configurations with a joint 4 axis perpendicular to the HPS surface.

Similarly, since the HPS mappings are done for only one plane (that is, at a constant Z height in the robot world coordinate frame), movements in the Z direction are not improved by using HPS data. Therefore, for calibration of horizontal cameras, the vertical axis of the camera is not improved at all when using HPS data. However, HPS data may still be useful for improving accuracy in the horizontal axis of the camera.

Calibration Target Dimensions

G

The Calibration Target 298
Using a Custom Calibration Sheet 299

The Calibration Target

The calibration target consists of black nested squares on a white background. Each square ring is numbered on the inside corner between it and the next smaller square ring. The inner and outer sides of the square rings are as follows:

Table G-1. Adept Calibration Sheet Dimensions

Square	Inside	Outside
1	0.993	1.194
2	1.427	1.727
3	2.065	2.461
4	2.926	3.508
5	4.173	5.030
6	5.974	7.160
7	8.517	10.262
8	12.169	14.635
9	17.407	20.935
10	24.854	29.868
11	35.502	42.700
12	50.719	60.998
13	72.433	87.147
14	103.485	124.506
15	147.848	177.853

Using a Custom Calibration Sheet

If you must create your own set of nested calibration squares, you can make the data available for them by altering or adding to the global array "ac.square.dims[,]". The format is as follows:

ac.square.dims[sheet,0]	0 (must be 0)
,1]	dimension of smallest white square.
,2]	outside of smallest black square.
,3]	outside of white square with 2 in it.
,4]	outside of black square with 2 in it.
,5]	outside of white square with 3 in it.
,6]	outside of black square with 3 in it.
,etc.]	

where "sheet" is 1 for the Adept Calibration Sheet. If you want your numbers to replace the existing ones for the Adept Calibration Sheet, then "sheet" should be 1. If you would like to add your sheet as an option to the standard sheet, then "sheet" should be 2 or more, but the sheet numbers must be consecutive starting from 1. If you do define more than one sheet's worth of square dimensions, then you will have to answer an additional question during calibration setup to indicate which sheet to use.

The identifying numbers on your custom sheet should be similar to the ones on the standard Adept Calibration Sheet, but there need not be so many nested squares. There must a pair of square dimensions for each number on the sheet. Since the numbers are printed in the white areas, the first number will be for the smallest square containing that number. The second number will be for the next largest square.

Assign your custom values into this array prior to executing the calibration package. Any sets of numbers predefined for any of the sheet numbers (including number 1) will be available for use as part of the normal operation of the program.

Camera Calibration Programs H

adv.cam.sample( ) 302
ac.refine.vloc( ) 303
adv.cam.user( ) and adv.tr.point( ) 305
    adv.cam.user( ) 305
    adv.tr.point( ) 308

adv.cam.sample( )

```
.PROGRAM adv.cam.sample()
; ABSTRACT:  This EXAMPLE PROGRAM (which is NOT MEANT TO BE EXECUTED)
;       shows how a camera may be used after it has been calibrated.
;
;* Copyright (c) 1988 by Adept Technology, Inc.

         LOCAL obj.loc, p, $error, $part
         $part = "anypart"                  ;Prototype name of interest

         ENABLE V.RECOGNITION

; Move to all defined picture-taking locations and look for part.

         FOR p = 1 TO LAST(picture.loc[])
              MOVE picture.loc[i]

; Call the user routine (use camera #1, don't have routine display errors).
; Global variable "to.cam[1]" must be the calibration transformation.

              CALL adv.cam.user(1, FALSE, $part, obj.loc, $error)
              IF $error <>"" THEN
                   TYPE "ERROR at part location", p, ":  ", $error
                   GOTO 100                 ;Skip to next site
              END

; Approach part and pick it up.  "grip" is a predefined transformation
; that defines the location on the part where it is to be gripped.

              APPRO obj.loc:grip, 50
              MOVE obj.loc:grip
              CLOSEI
              DEPART 50
; Place part in bin.

              APPRO part.bin, 50
              MOVE part.bin
              OPENI
              DEPART 50
    100   END
          RETURN
.END
```

ac.refine.vloc( )

The following program is supplied on the Advanced Camera Calibration disk in the file “ADV_USER.V2”. If this program is present when the calibration program is running, it will automatically be used to refine the location of vision locations to be used in calibration computations. Therefore, all calibration objects must be close to perfect circles, since this routine uses VFIND.ARC instructions to determine new centers for them.

```
.PROGRAM ac.refine.vloc(vloc, error)

; ABSTRACT:Refine the location of the circular blob at "vloc".
;
;   The current blob (region) in the queue (the last one
;   VLOCATEd) is the largest blob in the image that is not
;   touching the edges.  This routine assumes that it is a
;   circular disk and refines the location by performing a
;   VFIND.ARC with 100% effort level to get a new center value.
;                     .
;   Errors should be rare, since there is no good recovery.
;   In any case, the vloc should be returned unchanged when
;   refinement is not possible.
;
; INPUT PARM:  vloc     Current centroid of blob
;                       (already corrected for perspective distortion)
;
; OUTPUT PARM: loc      Revised vision location.
;              error    Pass back an error code
;                       (ec.no.disk, for example).
;
; SIDE EFFECTS: The edge strength is changed for the current virtual
;   camera.
;
;* Copyright (c) 1990 by Adept Technology, Inc.

         AUTO cx, cy, data[10], ok, radius, range, vb[14], xyr, ys
         error = 0                ;Do not return any errors.
         VGETCAL (ac.cam.virt) vb[]
         xyr = vb[vb.xy.ratio]
         ys = vb[vb.y.scale]*8

; Approximate radius, assuming the blob is a circle.

         radius = SQRT(VFEATURE(vf.area)*xyr/PI)*ys    ;Get radius
         cx = DX(vloc)
         cy = DY(vloc)
         range = 20*ys
```

```
; Use a window to compute an edge.strength at one third of maximum
; contrast.  Use a rectangle so will not fail if clipped.  Must be
; tall enough to catch some outside area when close to edge, but
; small enough to not reach to next ring.

        VWINDOWI (ac.cam.virt, 2, -1) data[] = 1, cx+radius, cy, ...
                                                 ... range, range*3
        PARAMETER V.EDGE.STRENGTH[ac.cam.virt] = (data[6]-data[5])/3

; Check the color of the pixels on the inside of the edge.

        VWINDOWI (ac.cam.virt, 0, -1) data[] = 2, cx, cy, ...
                          ... radius, radius-range/2, -10, 10
        IF (data[4]/data[3]) < .5 THEN     ;If mostly dark on inside,
            ok = 0                         ;Dark on inside of arc-finder.
        ELSE                               ; else,
            ok = 1                         ;Light on inside of arc-finder.
        END

; Do a VFIND.ARC to find the radius and center.

    ;VFIND.ARC modes bit field values:
    ; Circle color:  0 = dark, 1 = bright
    ; Find:  0 = center only, 2 = radius only, 4 = both
    ; Search position point:  0 = center, 8 = inner, 16 = outer

        VFIND.ARC (ac.cam.virt, ok+0+0, 1, 100) data[] = cx, cy, ...
                                            ... radius, range, 0, 0

; Check out the various indicators of failure.  Return no errors,
; just don't do the refinement.
;
; NOTE: The following messages, since written to the side bar,
; should not exceed 35 characters.  IF we use TYPEs then they can
; be much longer, but then they will go to the monitor window.

        IF data[0] == 0 THEN               ;If no arc found at all.
            WRITE (ac.sbl) /C1, "WARNING: VLOC refinement failed."
            GOTO 100
        END
        IF data[5] < 80 THEN           ;If less than 80% edges found.
            WRITE (ac.sbl) /C1, "WARNING: VLOC refinement weak."
             GOTO 100
        END
        IF data[6] > 5 THEN            ;If max err-dist more than 5 pixels.
             WRITE (ac.sbl) /C1, "WARNING: VLOC refinement in doubt."
             GOTO 100
        END

        SET vloc = TRANS(data[2], data[3])
```

```
; Done.

   100   RETURN
.END
```

adv.cam.user( ) and adv.tr.point( )

The following programs are supplied on the Advanced Camera Calibration disk in the file "ADV_USER.V2". These programs can be called by application programs to determine the location of an object as seen by a camera that has been calibrated with the Advanced Camera Calibration program.

adv.cam.user( )

```
.PROGRAM adv.cam.user(camera, display, $part, obj.loc, $error)

; ABSTRACT:  This is a user-callable subroutine that takes a picture
;   with the specified camera and returns the location (in the
;   robot coordinate system) of the object seen.  It is assumed
;   that the camera has been calibrated with the Adept Advanced
;   Camera Calibration program (in the disk file ADV_CAL.V2).
;   This will work for Adept-supported SCARA, XY, XYZ, and
;   XYZ-Theta configurations (including the UltraOne).
;
;   NOTE:     This routine assumes that the calibration was loaded
;   using the 10.3 version of the LOAD.AREA utility.  This
;   will insure that the link number that the camera is mounted
;   on will be in cal[3].
;
; INPUT PARM:  camera   Virtual camera number for the camera to use
;              display  Boolean (TRUE/FALSE) to request/suppress
;                       display of error messages on system monitor
;                       (assumed to be TRUE if not defined).
;              $part    String containing name of object to be found.
;                       Should be set to "?" if looking for any
;                       object.  If this is a NULL string (""), then
;                       it will be given the value of "?".
;
; OUTPUT PARM: $part    If this variable was set to "?" on input
;                       (see above), it is set by this routine to
;                       the name of the object found.
;              obj.loc  Location, in world coordinates, of the object
;                       found by the vision system.  (Set to NULL
;                       [and error reported] if no object is seen.)
;             $error    If no error occurs, this string variable is
;                       set to an empty string (""); otherwise, it
;                       is set to a string describing the error.
;
; SIDE EFFECTS: None
;
; DATA STRUCT:to.cam[]  This global transformation array must have an
;                       element defined for any camera that is accessed
;                       & that has a camera-to-robot calibration.
;
; MISC:  The V.BOUNDARIES and V.CENTROID system switches must be enabled
;   for the specified camera.  If a named object is requested, the
;   V.RECOGNITION switch must also be enabled.  In addition, other
;   switches and parameters must be set appropriate for the specific
;   application.
;
;* Copyright (c) 1988, 1989, 1990, 1991, 1992 by Adept Technology, Inc.

    LOCAL cal[], cal.type, jt[], mount, npics                        ;L04
    LOCAL link2, #pic.loc, vis.frame, vis.loc
    AUTO pcal[2,2], ipcal[2,2], pix[2], pmm[2]                       ;L34

    $error = ""                        ;Assume no error
    IF NOT LEN($part) THEN             ;If NULL, find any
        $part = "?"
    END

; Get calibration array for the camera and make sure it's okay.

    VGETCAL (camera) cal[], pcal[,], ipcal[,]                        ;L34

    IF cal[0] <> 2 THEN                ;Camera calibrated?
        $error = "* Camera not calibrated *"
        GOTO 100
    END
    cal.type = cal[2]                  ;Get the calibration method

; If camera has camera-to-robot calibration and calib. transformation
; is missing, return error '* "to.cam[n]" not defined *'.

    IF (cal.type <> 1) AND NOT DEFINED(to.cam[camera]) THEN
        $error = "* "+$CHR('"')+"to.cam["+$ENCODE(/I0,camera)
        $error = $error+"]"+$CHR('"')+" not defined *"
        GOTO 100                       ;Return with error
    END

; Get the link number that the camera is mounted on.                ;L19+

    mount = cal[3]                     ;Link number                  ;L04+;L34
```

```
; For robot-mounted camera, wait for motion to stop.  The appropriate
; amount of delay should be used for the particular robot and camera
; mounting bracket being used.

    IF mount THEN
        DELAY 0.2
        BREAK
    END

; Determine the vision coordinate frame relative to the robot
; coordinate system.
                                                                          ;L19-
    CASE mount OF

      VALUE 0:                          ;Fixed-mount camera
        IF cal.type == 1 THEN
           SET vis.frame = NULL         ;Camera-only calibration
        ELSE
           SET vis.frame = to.cam[camera]
        END

      VALUE 2:                          ;Camera on link #2
        HERE #pic.loc                   ;Determine current location
        DECOMPOSE jt[1] = #pic.loc      ;Extract joint positions
        SET link2 = HERE:INVERSE(TOOL):RZ(-jt[4]):TRANS(,,-jt[3])
        SET vis.frame = link2:to.cam[camera]

      VALUE 4:                          ;Camera on link #4
        SET vis.frame = HERE:INVERSE(TOOL):to.cam[camera]
    END                                                                   ;L04-

; Take pictures until "$part" is found or five pictures have been taken.

    npics = 0
    DO
         VPICTURE (camera)
         IF $part == "?" THEN
              VLOCATE (camera) $part, vis.loc
         ELSE
              VLOCATE (camera, 2) $part, vis.loc
         END
         npics = npics+1
    UNTIL VFEATURE(1) OR (npics > 5)

; If object was found, form location of object in world coordinates.
; Otherwise, return NULL location and error message.

    IF VFEATURE(1) THEN
    ; Convert the centroid to perspective millimeters if necessary.  ;L34+
    ; Do this by stripping off the basic calibration (to get back to
    ; camera pixels) and then applying the perspective calibration
    ; from the VGETCAL instruction.
    ; (See the vision manual, Appendix E, Perspective Distortion, for
    ; a description of the routine tr.point().)

        IF ipcal[2,0] OR ipcal[2,1] THEN
            pix[0] = DX(vis.loc)/(cal[4]*8*cal[14])  ;Strip off basic cal.
            pix[1] = DY(vis.loc)/(cal[4]*8)
            pix[2] = 1
            CALL adv.tr.point(ipcal[,], pix[], pmm[]);Apply persp cal.
            SET vis.loc = TRANS(pmm[0],pmm[1])
        END                                                            ;L34-

        SET obj.loc = vis.frame:vis.loc
    ELSE
        SET obj.loc = NULL
        IF $part == "?" THEN
            $error = "* No object seen *"
        ELSE
            $error = "* "+$CHR('")+$part+$CHR('")+" not seen *"
        END
    END

; Process any error that occurred.

100 IF $error <> "" THEN                     ;If there was an error...
        IF (ID(6) BAND ^HC0) THEN            ;Add camera number       ;S10
            $error = $MID($error,1,LEN($error)-1)
            $error = $error+"(virtual camera"+$ENCODE(camera)+") *"
        END
        IF NOT DEFINED(display) GOTO 110     ;Assume TRUE if not defined
        IF display THEN                      ;If display is enabled,
110         TYPE /B                          ; display error message
            TYPE "Error in ", $CHR('")+"adv.cam.user"+$CHR('"), /S
            TYPE ":  ", $MID($error,3,LEN($error)-4), /C1
        END
    END

    RETURN
.END
```

adv.tr.point( )

```
.PROGRAM adv.tr.point(trans[,], pt[], tpt[])

; ABSTRACT:  Transform a 2-D point given a 3x3 homogeneous transform.
;
```

```
; INPUT PARM:  trans[2,2]   3x3, 2-D homogeneous transform with pixel-
;                         to-mm scaling and compensation for
;                         perspective.
;              pt[2]      The coordinate to be transformed (the third
;                         value should be 1 unless you are scaling).
;
; OUTPUT PARM: tpt[2]     The transformed point, normalized so that
;                         the third value is 1.
;
; SIDE EFFECTS: None
;
;* Copyright (c) 1992 by Adept Technology, Inc.

    AUTO row, col, sum

    FOR row = 0 TO 2
         sum = 0
         FOR col = 0 TO 2
              sum = sum+trans[row,col]*pt[col]
         END
         tpt[row] = sum
    END
    tpt[0] = tpt[0]/tpt[2]
    tpt[1] = tpt[1]/tpt[2]
    tpt[2] = 1

    RETURN
.END
```

Pulnix TM-1001 Configuration

I

Introduction 312
Overview 312
Switch Settings 313
    DSP/NSP Switch 313
    NRM/ASY Switch 313
    Shutter Control 314
        For Asynchronous Reset Mode 314
        For Normal (Synchronous) Mode 314
EVI Module Settings 315
Camera Cables 315
Changes to Frame Buffer Size 315
Blob Analysis Using the Pulnix TM-1001 316

Introduction

This appendix describes how to set up the Pulnix TM-1001 camera. The camera must be purchased with the "Adept modifications".

⚠ **CAUTION:** An unmodified Pulnix TM-1001 camera will not work with Adept vision systems.

Overview

The Pulnix TM-1001 is operated in variable-scan mode with video carried over single-ended coax cable in the custom Hirose cable. Variable-scan mode means that the camera generates timing signals, including pixel clock, indicating the duration of a frame and the position of each image line and pixel within the video stream. The frame grabber on the vision board samples the video signal, using the frame enable, line enable, and pixel clock signals. The frame grabber is programmed with the vertical offset from the top of the frame (the number of lines to skip before valid image data), the horizontal offset from the left end of each image row (the number of pixels to skip at the beginning of each image row), and the height (number of lines per frame) and width (number of pixels per row) of the image. These four parameters determine the amount of the video signal that is used and also compensate for timing problems that may lead to missing lines at the top of the image, extra lines at the bottom of the image, missing pixels at the beginning of each row, or extra pixels at the end of each row.

In asynchronous with reset mode, when the camera receives a frame reset signal, it immediately stops the current frame, and starts a new frame. This allows the timing of the frame to be controlled precisely relative to other timing events. This capability also means that when a picture request is issued, the vision system does not have to wait until the camera finishes with the current frame before starting the requested frame, which would create a worst-case delay of one frame period (1/15 second).

The digital connector is not used in Adept vision systems. The BNC connector on the back of the camera has been modified to input the frame reset signal instead of output display video (for unmodified Pulnix cameras). The BNC connector cannot be used to display the camera image.

Switch Settings

This section describes the switch settings for the Pulnix TM-1001 camera.

DSP/NSP Switch

The Pulnix TM-1001 camera has a DSP/NSP switch located on the back of the camera (see **Figure I-1**).

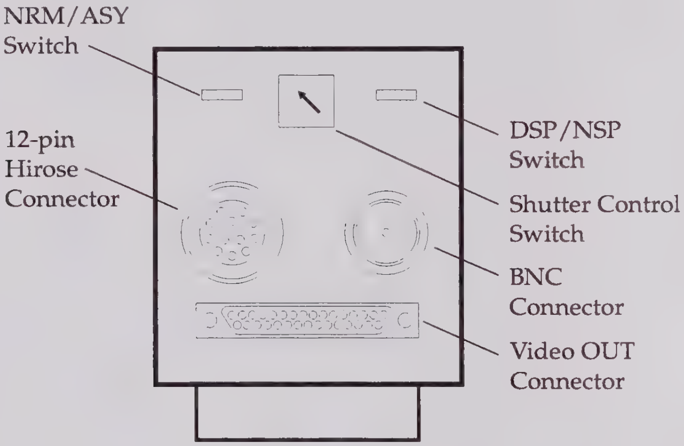


Figure I-1. Pulnix TM-1001 Camera Connectors and Switches

Always set the DSP/NSP switch to NSP. This switch is used in the Pulnix TM-1001 cameras that are not modified for Adept to change the frame rate from 15 to 30 frames per second. This allows the video signal that is normally carried on the BNC connector to be displayed on a monitor.

> **NOTE:** You cannot use the BNC connector to display images when using Pulnix TM-1001 cameras with the Adept modification.

NRM/ASY Switch

The Pulnix TM-1001 camera has two modes of operation—normal and asynchronous. The mode is determined by the position of the NRM/ASY switch located on the back of the camera (see **Figure I-1**). The switch positions are:

NRM	Normal Mode—used for synchronous mode
ASY	Asynchronous Mode (the resettable shutter is enabled)—used for asynchronous mode with reset.

Simply move the switch to the desired position to select the operating mode.

Shutter Control

The Pulnix TM-1001 has a shutter control rotary switch located on the back of the camera. (see Figure I-1). This section describes the shutter control settings that are currently supported.

For Asynchronous Reset Mode

For asynchronous reset mode, the camera should be operated with a shutter control setting of 5. See Table I-1 for details on other shutter dial settings for asynchronous mode.

> **NOTE:** Other settings may also work but would require adjustments to the camera timing registers. These settings have not been tested.
>
> Shutter setting 9 (external pulse width shutter) is not supported.

Table I-1. Shutter Dial Settings for Asynchronous Mode

Dial Setting	**Shutter Period (Lines)**	**Shutter Speed**	**Mode**
0		1/15	No shutter
1	1	1/16000	Fast
2	2	1/8000	
3	4	1/4000	
4	8	1/2000	
5	16	1/1000	Slow
6	32	1/500	
7	64	1/250	
8	128	1/125	

For Normal (Synchronous) Mode

For normal mode (not using asynchronous reset), the shutter control rotary switch can be set to any position depending on the shutter speed required for the application. The shutter dial settings for this mode are the inverse of those shown in Table I-1 with the exception of setting 0, which is no shutter for both modes.

- If your application has no motion during a frame, a shutter control setting of 2 (equals 1/125 shutter speed) is recommended.

- If your application has motion during a frame, a higher shutter setting is recommended. You must also open the aperture or increase the intensity of the lighting when operating at higher shutter settings.

EVI Module Settings

The Pulnix TM-1001 camera requires that an EVI module be installed in the Adept MV controller. This board has several sets of DIP and rotary switches that must be configured specifically for the Pulnix TM-1001 camera. See the *Adept MV Controller User's Guide* for details on EVI module switch settings.

Camera Cables

The Pulnix TM-1001 requires a special 4-camera (Hydra) cable and special breakout cable for attachment to the auxiliary connector on the 4-camera cable. Both of these cables can be purchased from Intercon 1.

For current part numbers, please contact Adept's **Application Questions** hotline or see the **Adept on Demand Web Page.**

To order, you can contact Intercon 1 at:

Intercon 1 Vision Products
Box 1C
Merrifield MN 56465
(800)237-9576 Voice
(218)765-3900 FAX

See the *Adept MV Controller User's Guide* for cabling details.

Changes to Frame Buffer Size

When using the Pulnix TM-1001 camera, you must change the frame buffer size to support the large-format camera. Do this by using the CONFIG_C utility to change the frame buffer size to 992 x 1024. (There is a 1024 x 1024 setting. However, several lines of the CCD are used for synching purposes. Therefore, the 1024 x 1024 option will not work correctly.)

NOTE: The vision window will be compressed by 50% (horizontally and vertically) to keep the large-format image on the monitor.

Blob Analysis Using the Pulnix TM-1001

When you perform blob analysis with the Pulnix TM-1001, the image is displayed somewhat differently than images acquired with other cameras. The actual image acquired is 992x1024, but it is stored in a frame that is 1024x1024 (this frame store size is specified using the DEVICE command). This difference in size leaves a black band on the right and bottom edges of the vision window. However, any blob processing that is performed is "clipped" so that this black band is ignored.

Using DEVICE With Vision J

Introduction 318

The DEVICE Instruction With Vision 318

Defective Pixel Compensation 321
Writing a Table Entry 321
Reading a Table Entry 322
Resetting a Table Entry 322
Error Information 322
Example: Changing the Number of Virtual Frame Stores 323

Introduction

The V+ DEVICE instruction can be used to:

- Reconfigure frame store sizes and memory allocations
- Read/modify camera interface registers[1]
- Read/modify camera model parameters[1]
- Read/modify vision constants[1]
- Write/read table of bad pixels for defective pixel compensation

CAUTION: When DEVICE is used to change frame store sizes or memory allocations, all models (prototypes, templates, fonts), AOI definitions, and VTRANS transformations are deleted and vision is re-enabled.

The DEVICE Instruction With Vision

The format for using DEVICE with the vision system is:

`DEVICE`

`(type, unit,` `status,` **`command, arg,`** `value`**`)`** `input[], output[]`

`type`	Must be 4 (to select vision).
`unit`	Set to 0.
`status`	Real variable that will be assigned an error code by the vision system. 1 = success; any other value = failure (use $ERROR to display error text).
`command`	1 = read/modify frame store sizes and memory allocations. Reenables menu events. 2 = read/modify camera interface registers[2] 3 = read/modify camera model parameters[1] 4 = read/modify vision constants[1] 5 = read/modify bad pixel coordinates

---

[1] For Adept-internal use only.

[2] For Adept-internal use only.

`arg`	0 = reset to defaults 1 = read current values 2 = write the values from `input[]`
`cam.virt`	Selects the virtual camera affected when **`command`** is 2. Selects the camera model number affected when **`command`** is 3. Ignored when **`command`** is 1 or 4.
`input[]`	Array of data values when **`arg`** is 2. This should not be specified when **`arg`** is 0 or 1.
`output[]`	Array of data that is filled by the vision system when **`arg`** is 1.

The `input[]` and `output[]` arrays always have the same format. So, if settings are read (**`arg`** = 1), then they can later be written (**`arg`** = 2) using the same array.

When **`command`** = 1, the `input[]` and `output[]` arrays have the format shown in Table J-1:

Table J-1. DEVICE Input/Output Format

Index	Contents
0	The number of elements that follow: 9
1	Number of the virtual frame store size in the range 1 to 6: 1=> 256x240 2=> 320x240 3=> 512x480 4=> 640x480 5=> 1024x1024 (Enhanced Vision Interface only) 6=> 1024x1024 (eliminated in V$^+$ version 12.0, but maintained for backward compatibility)
2	Blobs allocation in Kb
3	Object data structures allocation in Kb
4	Run lengths allocation in Kb
5	Bounds-in-box allocation in Kb
6	Unmatched bounds allocation in Kb
7	Allocation of AOIs in Kb
8	Allocation of VTRANS in Kb
9	Allocation of user LUTs in Kb

Elements 2 through 7 are memory allocations in units of kilobytes. (The default amount of total memory allocated for the vision system software has been increased from 1.25Mb to 1.5Mb.) These values should be in the range specified in Table J-2. If a value outside the range is specified, the closest in-range value is used. If a given value is 0, then the default allocation is used. If the allocation size doubles, the number of items doubles. A few of the default allocations differ depending on the image size. Table J-2 applies to a 512x480 image setup.

Table J-2. Vision Memory Allocation

	Allowed Range in Kb	Default Kb	Item Size	Approx. # items	Bytes Used
Blobs alloc:	4 to 512	28	32	875	28000
Objects alloc:	4 to 800	77	116	663	76908
Run-lengths alloc:	4 to 255	125	4	31250	125000
Bounds-in-box alloc:	1 to 40	4	56	71	3976
Unmatched alloc:	2 to 56	30	12	2500	30000
AOIs alloc:	1 to 100	6	28	214	5992
VTRANS alloc:	1 to 100	1	48	20	960

Table J-2. Vision Memory Allocation (Continued)

	Allowed Range in Kb	**Default Kb**	**Item Size**	**Approx. # items**	**Bytes Used**
User LUT alloc:	1 to 33	1	258	3	774

NOTE: If the total of the above allocations does not leave at least 190Kb of free space, an error is returned.

Defective Pixel Compensation

The DEVICE command can be used to read/write a table of bad pixel locations. These tables are generated from reports that are typically provided by the camera manufacturer.

NOTE: Defective pixel compensation can be used with any camera.

The table of bad pixel location is an array of coordinates. Element 0 is the number of coordinates (it will be twice the number of pixels) and array elements `coords[1]` through `coords[coords[0]]` are the x and y coordinates of the bad pixel locations. The coordinates are specified relative to the AOI of the virtual frame buffer into which the frame is grabbed. However, (0,0) refers to the upper-left pixel with x increasing as you move to the right, and y increasing as you move down. This coordinate system is used since the reports on bad pixel locations provided by the camera vendors assume a coordinate system with the y axis pointing down (row/line number increases) and with (0,0) at the upper left of the camera imaging sensor.

NOTE: Refer to the beginning of this section for a description of the DEVICE command parameters.

Writing a Table Entry

To write the bad pixel coordinates for pixel compensation table entry `i`, use the following DEVICE command:

```
DEVICE (4, 0, status, 5, 2, i) coords[]
```

Up to eight pixel compensation tables can be defined using this DEVICE instruction. The intent is that each compensation table can be associated with an actual camera. (Since different cameras can be attached to different camera ports, there is no way for the system to know which pixel compensation table (if any) should be associated with a given virtual camera.)

The pixel compensation table(s) can be defined with DEVICE instructions, and then a particular compensation table, identified by its index in the range 1 - 8, can be associated with a virtual camera using the following code:

```
VGETCAL (cam) table[]
table[18] = index
VPUTCAL (cam) table[]
```

Once a defective pixel compensation table is associated with a virtual camera, the pixels in the bad locations will be replaced with an average of the surrounding pixels that are not defective. The replacement will happen automatically between the time that a frame is grabbed and is made available for processing.

Reading a Table Entry

To read the bad pixel coordinates for pixel compensation table entry `i`, use the following DEVICE command:

```
DEVICE (4, 0, status, 5, 1, i) coords[]
```

Resetting a Table Entry

To reset table entry `i` to the initial state (no coordinates provided for that entry, and no pixel compensation performed), use the following DEVICE command:

```
DEVICE (4, 0, status, 5, 0, i)
```

Error Information

The `status` parameter is a return code for error information. If `status` <>1, an error occurred. See the information at the beginning of **"The DEVICE Instruction With Vision" on page 318** for details.

The possible reasons for errors are invalid arguments or being out of system memory. An "out of system memory" error can happen only when the DEVICE command is unable to allocate space for the array of pixel coordinates from system memory.

The DEVICE command (**`type`** parameter 4) will return an error (such as device not ready) on the AdeptWindows interface if there is a task running that has executed a D* graphics command. To fix this problem temporarily, abort and kill those tasks and retry the command. To permanently fix this problem, convert the programs that currently use D* graphics commands to use G* graphics commands.

Example: Changing the Number of Virtual Frame Stores

The following code will change the number of virtual frame stores to six 320 x 240 frame stores (twelve 320 x 240 frame stores with the Enhanced Vision Interface). Make sure all vision models have been saved before running this code:

```
; Get the current configuration

    DEVICE(4, 0, error, 1, 1), vis_config[]
    IF error <> 1 GOTO 100

; Alter element 1 of the output array

    vis_config[1] = 2

; Write the new configuration

    DEVICE(4, 0, error, 1, 2) vis_config[]
    IF error <> 1 GOTO 100

100; Handle errors
```

The following code will change the space allocated for blobs to 24Kb and the allocation for object data structures to 500Kb. Make sure all vision models have been saved before running this code:

```
; Get the current configuration

    DEVICE(4, 0, error, 1, 1), vis_config[]
    IF error <> 1 GOTO 100

; Alter elements 2 and 3 of the output array

    vis_config[2] = 24
    vis_config[3] = 500

; Write the new configuration

    DEVICE(4, 0, error, 1, 2) vis_config[]
    IF error <> 1 GOTO 100

100; Handle errors
```

Memory Allocation K

In certain situations, the Blob Finder and ObjectFinder tools may cause out-of-memory errors when used with the FlexFeeder. To correct this, the default system memory allocation was increased to 1.5Mb for V$^+$ version 12.1. Specifically, the values for run-lengths, blobs, and objects for the vision queue have been increased.

The table below details the default memory allocations and provides suggested values for certain situations.

Table K-1. Vision System Memory Allocation

	Range (Kb)	**Default (Kb)**	**Size of Item**	**# Items**
Default memory allocations for pre-12.1 software (1.25Mb total memory):				
Blobs	4 to 32	28	32	.8
Objects	4 to 800	77	116	.6
Run-lengths	4 to 126	125	4	31.1
TOTAL		230		
Default memory allocations for version 12.1 software (1.5Mb total memory):				
Blobs	4 to 512	28	32	.8
Objects	4 to 800	77	116	.6
Run-lengths	4 to 255	125	4	31.1
TOTAL		230		
Suggested allocations for version 12.1 software when using ObjectFinder with FlexFeeder images:				
Blobs	4 to 512	50	32	1.5
Objects	4 to 800	100	116	.8

Table K-1. Vision System Memory Allocation (Continued)

	Range (Kb)	**Default (Kb)**	**Size of Item**	**# Items**
Run-lengths	4 to 255	200	4	50.0
TOTAL		350		
Suggested allocations for version 12.1 software with 1K x 1K frame buffers (requires the EVI module):				
Blobs	4 to 512	100	32	3.0
Objects	4 to 800	100	116	0.8
Run-lengths	4 to 255	255	4	63.7
TOTAL		455		
Maximum allocations:*				
Blobs	4 to 512	50	32	1.5
Objects	4 to 800	100	116	.8
Run-lengths	4 to 255	200	4	50.0
TOTAL		350		

* Provided for illustration only (maximum values are rarely needed). Total vision system memory allocation must be changed to 4.0Mb using the CONFIG_C utility.

Vision Window Menus

L

Cam/frame	
✔ Frame #11	Select the frame store for the next image acquire.
" #21	
" #12	
" #22	
✔ Camera #1	Select the camera to use for the next image acquire. This option selects a physical/virtual camera pair. You cannot select different physical/virtual camera pairs using this menu option.
" #2	
" #3	
" #4	

Display	
✔ Live grayscale (VDISP –1,0)	Display the live video input from the selected camera.
Live binary (VDISP 0,0)	Display the live thresholded image from the selected camera.
Grayscale frame (VDISP 1,0)	Display the image in the selected grayscale frame store.
Binary frame (VDISP 2,0)	Display the image in the selected binary frame store.
Graphics only (VDISP 3)	Display a processed image and any tool or user graphics.
Static graphics (VDISP 4)	Don't erase graphics with each picture operation.
✔ Graphics overlay (VDISP *,1)	Display tool and user graphics over live video or frame image.
Static overlay (VDISP *,2)	Overlay graphics; don't erase with each picture operation.

Pict	
Acquire (VPICT 2)	Acquire an unprocessed image (quick frame grab).
Process (VPICT 0)	Process image in frame store selected from **Cam/frame** menu.
Acquire & process (VPICT –1)	Acquire & process image (frame selected from **Cam/frame** menu).

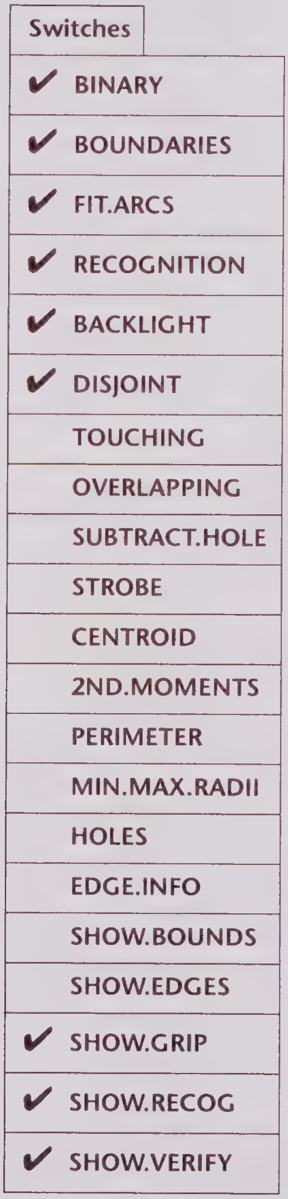
Ops	
Histogram	Display histogram showing frequency of each graylevel value.
Auto-threshold	Generate recommended values for V.THRESHOLD.
Copy frame 11 to 12	Copy image data between the two frame stores.
Convolve 3x3 average	Perform a convolve operation on the selected frame store. See the description of VCONVOLVE in the *AdeptVision Reference Guide* for details on image convolutions.
" 5x5 average	
" (custom #17)	
Subtract grayscale, 11-12	Subtract the grayscale or binary values in physical frame store 1 from the physical frame store 2. See the description of VSUBTRACT for details on image subtraction.
" binary, "	
Add grayscale, 11+12	Add the grayscale or binary values in physical frame store 1 to the physical frame store 2. See the description of VADD for details on image addition.
" binary, "	
Average grayscale, 11 and 12	Average graylevels in the two frame stores.
Binary threshold	Show edges found based on the value of V.THRESHOLD.
Gray. edges, Gradient	Show edges found based on the value of V.EDGE.STRENGTH using either the standard gradient operator or the Sobel operator. See the description of V.EDGE.TYPE.
" " Sobel	
Morph. erosion	Perform a morphological operation on the selected image. See the description of VMORPH in the *AdeptVision Reference Guide* for details on morphological operations.
" dilation	
" (custom #9)	

Status	
Status	Display the status of the vision system.
Abort processing	Abort any active vision processing (prototype planning, for example).

Models	
Train prototype	Initiate training of a new or existing prototype model.
List prototypes	List all prototypes currently in vision memory.*
Show prototype	Display a prototype model.
Rename prototype	Rename a prototype model (not a file of prototypes).
Delete prototype	Delete a prototype of vision memory (not from disk).
List fonts	List all fonts currently in vision memory.*
Show font	Display a loaded font.
Rename font	Rename a font (not a file of fonts).
Delete font	Delete a font from vision memory (not from disk).
List templates	List correlation templates in vision memory.*
Show template	Display a template currently in vision memory.
Rename template	Rename a template (not a file of templates).
Delete template	Delete a template from vision memory (not from disk).

* See the description of VLOAD for details on loading vision models to vision memory.

The **Switches** menu shows all the vision switches. A "✔" next to the switch indicates the switch is enabled for the selected camera (selected under the **Cam/frame** menu).



	Switches	
✔	BINARY	Select binary or edge processing.
✔	BOUNDARIES	Enable/disable boundary analysis.
✔	FIT.ARCS	Enable/disable arc fitting during boundary analysis.
✔	RECOGNITION	Enable/disable prototype recognition.
✔	BACKLIGHT	Select light background or dark background.
✔	DISJOINT	Enable/disable prototype recognition of disjoint regions.
	TOUCHING	Enable/disable prototype recognition of touching objects.
	OVERLAPPING	Enable/disable prototype recognition of overlapping objects.
	SUBTRACT.HOLE	Subtract hole area(s) for calculated region areas.
	STROBE	Enable/disable sending of strobe signal at image acquisition.
	CENTROID	Enable/disable calculation of centroid data.
	2ND.MOMENTS	Enable/disable calculation of 2nd moment data.
	PERIMETER	Enable/disable calculation of region perimeters.
	MIN.MAX.RADII	Enable/disable calculation of region min. and max. radii.
	HOLES	Enable/disable calculation of VFEATURE( ) data on holes.
	EDGE.INFO	Enable/disable calculation of edge data (see VEDGE.INFO).
	SHOW.BOUNDS	Show boundaries calculated during boundary analysis.
	SHOW.EDGES	Show edges calculated when an image is processed.
✔	SHOW.GRIP	Show the effects of clear grip tests (see VDEFGRIP).
✔	SHOW.RECOG	Show prototype silhouettes on top of recognized prototypes.
✔	SHOW.VERIFY	Show all attempts at prototype recognition.

Resolution	
Full Resolution	Display the image at maximum resolution.
Half Resolution	Display the image at one-half of maximum resolution.
Quarter Resolution	Display the image at one-quarter of maximum resolution.
Focus Mode	Display a portion of the image at the center of the window at full resolution.

Third-Party Suppliers M

Third-Party Suppliers (U.S.) 334
  Fiber Optic Lighting Suppliers 334
  Lighting Suppliers 335
  Camera Equipment Suppliers 335
  Frame Splitter Suppliers 336
  Camera Suppliers 336
  Filter and Optics Suppliers 337
  Lens Suppliers 337
Third-party Suppliers (Europe) 339
  Mounting Hardware Suppliers 339
  Lighting Suppliers 339
  Lens Suppliers 340
  Filter and Optics Suppliers 340
Third-Party Suppliers (Asia-Pacific) 343
  Lighting, Filter, and Optics Suppliers 343

Third-Party Suppliers (U.S.)

Table M-1. Fiber Optic Lighting Suppliers

Manufacturer	**Product Line**
Dolan-Jenner Industries, Inc. 678 Andover St. Lawrence, MA 01843 Phone: (508) 681-8000 Fax: (508) 682-2500	Fiber-Lite illuminators; annular, single-head, and dual-head fiber optic cables.
Fostec, Inc. 62 Columbus St. Auburn, NY 13021 Phone: (315) 255-2791 Fax: (315) 255-2695	Optical fiber bundles (medium quality, good price)
General Fiber Optics, Inc. 1 Washington Ave. Fairfield, NJ 07004 Phone: (201) 239-3400 Fax: (201) 239-4258	Fiber optic arrays, flexible image guides, illumination bundles, fiber optic cables
Moritex Corp. 6440 Lusk Blvd. San Diego, CA 92121 Phone: (619) 453-7905 Fax: (619) 453-7907	DC Fiberlight, fiber bundles
Volpi Manufacturing USA 5 Commerce Way Auburn, NY 13021 Phone: (315) 255-1737 Fax: (315) 255-1202	Fiber optic light sources and cables in various shapes including single and dual head, annular, and linear

Table M-2. Lighting Suppliers

Manufacturer	**Product Line**
Aristo Grid Lamp Products, Inc. 35 Lumber Rd. Roslyn, NY 11576-2105 Phone: (516) 484-6141 Fax: (516) 484-6992 Internet: www.aristogrid.com	Mic-O-Lite ring lights
Cool-Lux Lighting Industries, Inc. 5723 Auckland Ave. N. Hollywood, CA 91602-2207 Phone: (818) 761-8181 Fax: (818) 761-3202	Mini-Cool lights
E. G. & G. Electro Optics 35 Congress Street Salem, MA 01970 Phone: (508) 745-3200 Fax: (508) 745-0894 Internet: www.egginc.com	Strobe lights
Honeywell Microswitch / Visitronic 11 West Spring St., Freeport, IL 61032 Phone: (815) 235-6600 Fax: (815) 235-5574	Industrial light sources that provide direct, diffused, collimated, patterned, or fiber optic illumination. NEMA-12 lighting, halogen DC lamps.
Magnatek (formerly Triad) 305 North Briant Huntington, IN 46750 Phone: (219) 356-7100 Fax: (219) 356-3148	High frequency electronic ballasts for fluorescent lights
Stocker & Yale, Inc. Phone: (603) 893-8778 Fax: (603) 893-5604 Internet: www.stkr.com	Lite Mite ring lights
Vision Engineering Laboratories, Inc. 1360 72nd St. North Largo, FL 34647 Phone: (813) 545-0018 Fax: (813) 545-0525	Standard and custom strobe lights, power supplies, and systems for machine vision
Lasiris, Inc. 3549 Ashby Saint-Laurent Quebec, Canada H3R 2K3 Phone: (514) 335-1005Fax: (514) 335-4576	Laser based structured light generators. Single line (1-33 lines), concentric, and special patterns are available

Table M-3. Camera Equipment Suppliers

Manufacturer	**Product Line**
Bogen 565 East Crescent Ave., P.O. Box 506 Ramsey, NJ 07446 Phone: (201) 818-9500 Fax: (201) 818-9177 Internet: www.bogenphoto.com	"Magic Arms"–flexible fixturing for cameras, lighting, parts, etc. "Copy stands"–Camera mounting stand with vertical stage.

Table M-3. Camera Equipment Suppliers (Continued)

Manufacturer	**Product Line**
Desoutter, Inc. 11845 Brookfield Ave. Livonia, MI 48150 Phone: (313) 522-1466Fax: (313) 522-7010	Mechanical columns, clamps, and other machine vision mounting hardware
R.K. Industries 7330 Executive Way Frederick, Maryland 21701 Phone: (301) 696-9400 Fax: (301) 696-9494	Phoenix Mechano modular mounting systems, steel and aluminum, round and square tube and clamp systems
Worksmart Systems, Inc. 33 Ship Avenue Medford, MA 02155 Phone: (617) 396-0650 Fax: (617) 391-9150	Modular mounting systems for cameras, monitors, terminals, etc., aluminum tubing and clamps
Intercon 1, Inc. Box 1C Merrifield, MN 56465 Phone: (800) 237-9676Fax: (218) 765-3900	Standard and custom camera cables, junction boxes

Table M-4. Frame Splitter Suppliers

Manufacturer	**Product Line**
American Sound 1800 Russel St. Covington, KY 41014 Phone: (606) 261-9024 Fax: Same as phone	Frame splitter combines two camera inputs into one for higher speed–part number AD1470A

Table M-5. Camera Suppliers

Manufacturer	**Product Line**
Sony Corporation of America 10833 Valley View Street P.O. Box 6016 Cypress, California 90630-0016 Phone: (714) 220-9100 Fax: (714) 229-4298	Sony XC-77RR (shuttered) cameras–compatible with AdeptVision AGS EMUX.

Table M-6. Filter and Optics Suppliers

Manufacturer	**Product Line**
Aerotech World Headquarters 101 Zeta Drive, Pittsburgh, PA 15238 Phone: (412) 963-7470Fax: (412) 963-7459 Internet: www.aerotech.industry.net	Electro-optical components; mirrors, lasers, positioning stages
Ealing Electro-Optics 89 Doug Brown Way Holliston, MA 01746 Phone: (800) 343-4912 Fax: (508) 429-7893 Internet: www.ealing.com	Electro-optical components; optical benches, prisms, filters, light sources, lasers, lenses, mirrors
Edmund Scientific 101 E. Glouster Pike Barrington, NJ 08007 Phone: (609) 573-6260 Fax: (609) 573-6295 Internet: www.edsci.com	Scientific and optical supplies; prisms, lenses, optical bench hardware
Melles Griot 1770 Kettering St. Irvine, CA 92614 Phone: (800) 835-2626 Fax: (714) 261-7589	Filters, lasers, prisms, optics, positioning devices, optical benches, polarizers
Newport Corp. 1791Deere Ave. Irvine, CA 92602 Phone: (714) 965-5406 Fax: (714) 963-2016	Electro-optical components for machine vision, filters, lasers, structured lighting, optical benches
Tiffin Manufacturing 90 Oser Ave. Hauppauge, NY 11788-3886 Phone: (516) 273-2500 Fax: (516) 273-2557	Filters, lenses

Table M-7. Lens Suppliers

Manufacturer	**Product Line**
ESCO Products, Inc. 171 Oak Ridge Road Oak Ridge, New Jersey 07438 Phone: (201) 697-3700 Fax: (201) 697-3011	Custom-made lenses, prisms, filters, beamsplitters, and machining services
Nikon, Inc. Instrument Group 1300 Walt Whitman Rd. Melville, NY 11747 Phone: (516) 547-4200 Fax: (516) 547-0299 Internet: www.nikonusa.com	Precision 35mm format lenses

Table M-7. Lens Suppliers (Continued)

Manufacturer	Product Line
R.O.I. Industries 1791 Deere Ave. Irvine, CA 92602 Phone: (714) 895-1880 Fax: (714) 224-0550 Internet: www.ramoptical.com	OVP, optical video probe VDZ, video direct zoom Right angle probes
Schneider Optics, Inc. 285 Oser Ave. Hauppage, NY 11788 Phone: (516) 496-8500 Fax: (516) 496-8524 (800) 645-7239 Internet: www.schneideroptics.com	High-quality C-mount lenses with very low distortion
Toyo Optics 580 W. Lambert Rd., Suite H Brea, CA 92821 Phone: (714) 529-4688 Fax: (714) 529-5766	Cosmicar C-mount lenses, extension tubes, and accessories

Third-party Suppliers (Europe)

Table M-8. Mounting Hardware Suppliers

Manufacturer	Product Line
Lino Manfrotto & Co. Zona Industriale di Campese Via Sasso Rosso 19 36061 Bassano del Grappa, Italy Phone: +39 424-80 80 43 Fax: +39 424-80 89 99	"Magic Arms" - flexible fixturing for cameras, lighting, parts, etc.
Rose + Krieger GmbH & Co KG Potsdamer Str. 9 32423 Minden, Germany Phone: +49-571/93 350Fax: +49-571/93 35 119	Modular mounting systems, steel and aluminum, round and square tube and clamp systems.

Table M-9. Lighting Suppliers

Manufacturer	Product Line
Polytec GmbH Polytec Platz 1-7 76337 Waldbronn, Gernamy Phone: +49-72 43/60 41 73 Fax: +49-72 43/69 944	Ring lights, fiber optics and filters.
Dolan-Jenner Europe B.V. P.O. Box 345 AH Uden, Holland Phone: +31-41 32/63 930 Fax: +31-41 32/60 938	Ring lights and fiber optics.
R.Y.F. Optical Instruments Bettlaschstr. 2 2540 Grenchen, Switzerland Phone: +41-32/65 25 484 Fax: +41-32/65 33 612	Lite Mite ring lights
Volpi AG Wiesenstrasse 33 8952 Schlieren, Switzerland Phone: +41-1/73 09 761 Fax: +41-1/73 09 044	Fiber optic illuminators in various shapes including ring and linear

Table M-10. Lens Suppliers

Manufacturer	**Product Line**
Chugai Boyeki (Deutschland) GmbH Hansaallee 191 40549 Düsseldorf, Germany Phone: +49-211/53 06 70 Fax: +49-211/53 06 71 80 Chugai Boyeki (U.K.), Ltd. Computar House 6 Garrick Industrial Centre Garrick Road, London NW 9 6AQ, England Phone: +44-181/732 33 33 Fax: +44-181/202 33 87 Chugai Boyeki Milano Via Carolina Romani 1/11 20091 Bresso (MI), Italy Phone: +39-2/66 50 32 10 Fax: +39-2/66 50 32 04 Chugai Boyeki Paris Europarc, 15-33 Rue Le Corbusier 94035 CRETEIL CEDEX, France Phone: +33-1/43 99 04 24 Fax: +33-1/43 99 59 06 Internet: www.chugai.com	C-mount lenses, extension tubes, range finders, 35mm format lenses
Joseph Schneider Optische Werke Kreuznach GmbH Ringstrasse 132 55543 Bad Kreuznach, Germany Phone: +49-671/60 10Fax: +49-671/60 11 09	High-quality C-mount lenses with very low distortion

Table M-11. Filter and Optics Suppliers

Manufacturer	**Product Line**
Aerotech Gmbh Neumeyerstr 90 90411 Nürnberg, Germany Phone: +49-911/52 14 540Fax: +49-911/52 14 54 30	Electro-optical components; filters, mirrors, positioning stages.
Ealing Electro-Optics plc Greycaine Road Watford WD2 4PW, England Phone: +44-19 23/24 22 61Fax: +44-19 23/23 42 20 Internet: www.ealing.com	Electro-optical components; light benches, prisms, filters, light sources, mirrors

Table M-11. Filter and Optics Suppliers (Continued)

Manufacturer	**Product Line**
Melles Griot–France Parc du Mérantais 1, Rue de Guynemer 78114 Magny Les Hameaux, France Phone: +33-1/30 12 06 80Fax +33-1/30 60 08 51 Melles Griot–Germany Lilienthalstr. 30-32 64625 Bensheim, Germany Phone: +49-62 51/84 060Fax: +49-62 51/84 06 22 Melles Griot–Netherlands Hengelder 23, P.O. Box 272 6900 AG Zevenaar, Netherlands Phone: +31-316/33 30 41Fax: +31-316/52 81 87 Melles Griot, Ltd.–United Kingdom 2, Pembroke Avenue Waterbeach Cambridge, CB5 9QR, United Kingdom Phone: +44-12 23 20 33 00Fax: +44-12 23/20 33 11 Internet: www.mellesgriot.com	Mirrors, prisms, filters, polarizers, lasers, optical benches, component holders, positioning devices
Newport GmbH–Germany Holzhofallee 19 64295 Darmstadt, Germany Phone: +49-61 51/36 210Fax: +49-61 51/36 21 50 Newport, Ltd.–U.K. 4320 First Avenue Newbury Business Park London Road, Newbury Berkshire, RG13 2PZ, United Kingdom Newport Instruments AG–Switzerland Giessenstrasse 15, 5th Floor 8952 Schlieren, Switzerland Phone: +41-17 40/22 83Fax: +41-17 40/25 03	Electro-optical components for machine vision, filters, lasers, structured lighting, optical benches

Table M-11. Filter and Optics Suppliers (Continued)

Manufacturer	**Product Line**
L.O.T. - Oriel Ltd. 1 Mole Business Park Leatherhead, Surrey KT22 7AU, United Kingdom Phone: +44-13 72/37 88 22Fax: +44-13 72/37 53 53 L.O.T. - Oriel S.A. 9 Avenue De Laponie Z.A. De Courtaboeuf 91951 Les Ulis Cedex, France Phone: +33-1/60 92 16 16Fax: +33-1/60 92 16 10 L.O.T. - Oriel GmbH Im Tiefen See 58 64293 Darmstadt, Germany Phone: +44-61 51/88 060Fax: +44-61 51/89 66 67 L.O.T. - Oriel Italia Viale Dei Mille, 20 20129 Milano, Italy Phone: +39-2/70 12 69 38Fax: +39-2/70 12 67 67	Lenses, filters, polarizers, mirrors, prisms, beam splitters, fiber optics

Third-Party Suppliers (Asia-Pacific)

Table M-12. Lighting, Filter, and Optics Suppliers

Manufacturer	Product Line
Barnin Enterprises Co., Ltd. (Oriel Scientific, Ltd.) P.O. Box 87-594 Taipei, Taiwan (R.O.C.) Phone: 02-760-5513 Fax: 02-763-1231	Lenses, filters, polarizers, mirrors, prisms, beam splitters, fiber optics
Dolan-Jenner Europe BV Bas Straat 4 5402AG Uden, Netherlands Phone: 04-132-639-30	Fiber optic light sources and cables
E.G.&G. Ireland, Ltd. Electro-Optics Division Bay D3/4 Shannon Industrial Estate County Clare, Ireland Phone: 353-61-62577 Fax: 353-61-62390	Strobe lights
Harvin Agencies (Oriel Scientific, Ltd.) 6-3 1090/B/4 Raj Bhavan Road Soma Jiguda Hyderabad-500 482 AP, India Phone: 36858	Lenses, filters, polarizers, mirrors, prisms, beam splitters, fiber optics
Ing. Volker Hippe auf der Platte 32 D-6000 Frankfurt/Main 50, Germany Phone: 069-545470	Line stripe projectors
Keehwa Enterprise Corp. (Oriel Scientific, Ltd.) Ha Nam Bldg., Suite 906 44-27 Yedeudo-Dong Yeoung Dung Po-Ku (Oriel Scientific, Ltd.) Seoul, Korea Phone: 783-7396Fax: (02) 784-3935	Lenses, filters, polarizers, mirrors, prisms, beam splitters, fiber optics

Table M-12. Lighting, Filter, and Optics Suppliers (Continued)

Manufacturer	**Product Line**
Leonix Corp. (Oriel Scientific, Ltd.) Mutsumi Building 4-5-21 Kohjimachi Chiyoda-Ku Tokyo 102, Japan Phone: 03-239-3090 Fax: 03-239-3191	Lenses, filters, polarizers, mirrors, prisms, beam splitters, fiber optics
Melles Griot–Japan Towa Bldg. 3F, 2-16-3 Shibuya Shibuya-ku, Tokyo, Japan Phone: (03) 407-3613 Fax: (03) 486-0923 Melles Griot–Taiwan #2, Industrial E. Road III Science-Based Industrial Park Hsinchu, Taiwan, R.O.C. Phone: (35) 775-111 Fax: (35) 776-182 Melles Griot–Singapore 105 Sims Avenue #03-12 Chancerlodge Complex Singapore 1438 Phone: 743-5884 Fax: 743-4524 Melles Griot–Hong Kong 3/F, Room 6 Hilton Center, Tower A Shatin, Hong Kong Phone: (852) 691-4921 Fax: (852) 603-0285	Mirrors, prisms, filters, polarizers, lasers, optical benches, component holders, positioning devices
Marubun Corporation (Newport Corp.) 8-1 Nihombashi Odemmacho Chuo-Ku, Tokyo, 103 Japan Phone: 03-648-8115 Fax: 03-648-9398	Electro-optical components for machine vision, filters, lasers, structured lighting, optical benches
Moritex Corp. Fiber Optics Department Sakuragoaka-cho, 8-9 Shibuya-ku Meisei Bldg., Tokyo 150, Japan Phone: 03-476-1021 Fax: 03-476-1698	DC Fiber light, fiber optic cables
Quentron Optics Pty. Ltd. (Oriel Scientific, Ltd.) Laser Court, 75A Angas St. Adelaide 5001, South Australia Phone: (08) 223-6224 Fax: (08) 223-5289	Lenses, filters, polarizers, mirrors, prisms, beam splitters, fiber optics
Spectra Physics Pty., Ltd. (Newport Corp.) 2-4 Jesmond Road Croydon, Victoria, Australia Phone: 03-723-6600 Fax: 03-725-4822	Electro-optical components for machine vision, filters, lasers, structured lighting, optical benches

Index

A

a.adv_cal (program) 73
ac.config[ ] (real array) 110
ac.dot.loc (location) 99, 101
ac.nominal[ ] (location array) 93, 110
ac.offset[ ] (location array) 94, 109
ac.refine.vloc (program) 303
Acquiring an image 114
  and begin processing 200
  unprocessed 114
Address, E-mail 27
Adept
  calibration sheet dimensions 298
  fax back service 28
  web page 28
AdeptVision Reference Guide 24
ADJUST
  binary THRESHOLD (live binary) 90
  camera/image
    menu 89
    menu options 89
    settings 86
  physical CAMERA ATTRIBUTES (live video) 89
  video GAIN and OFFSET (live video) 90
  vision WINDOW (processing boundaries) 90
Adjusting camera settings 89
adv.cam.sample (program) 302
adv.cam.user (program) 305
adv.tr.point (program) 308
ADV_CAL 54
ADV_CAL.V2 72
ADV_CAL.V2 disk file 65, 72, 73
ADV_USER.V2 disk file 303, 305
ADV_USER.V2, details on 75
Advanced Calibration Program
  main menu 84
    options 84
AIO.IN 33
AIO.OUT 33
AOI (see area-of-interest)
Application
  development strategy 194
  flow chart 197
  questions 27
Applications Support, internet e-mail address 27
Arc ruler 155
  example 155, 157
Arc-shaped area-of-interest shapes 148
Area vision calibration program
  calibration target dimensions 298
AREACAL 54
  using to load calibration data 57
Area-of-interest 146–??
  shapes 148
Arm-mounted camera 229
  calibration 56
Array, calibration (see Calibration array)
Assign cameras 178
  prototype parameter 178
Assigning camera numbers 54
Asynchronous Reset Mode 314
ATTACH 33
Attaching cameras and strobes 44

B

Backlighting 291
Before calibrating your cameras 65
Binary
  defined 36
  image 36
    example 36
  representation of sample matrix 119
  threshold 90
  vs. grayscale modes 118
Blob
  allocation 142
  analysis 136
    using the Pulnix TM-1001 316
  recognition 139

Blob-relative inspection 255, 257
Boundaries, vision window 90
Boundary analysis 39, 136
  defined 39
  instructions 138
  parameter 137
  switches used with 136
  switches 136
Brightness, adjusting image 89

C

Calculating the "Link2" transformation 232
Calculating the object tail location 219
CALIBRATE 55
CALIBRATE the current camera
  menu 91
  menu options 95
Calibrating
  a camera 54
  with HPS data 294
Calibrating the current camera 86
Calibration
  arm-mounted camera 56
  array 106
    neg.angle entry 108
    v.pitch entry 108
  data
    loading 57
  fixed-mount camera 55
  menu
    link-2 mounted camera
      known dot location 101
      non-contact method (lefty/righty) 102
      non-contact method (single config.) 101
      robot can touch calibration object 100
    Robot mounted camera
      known dot location 99
      robot can touch calibration object 98
    robot mounted camera
      non-contact method 99
    Stationary camera
      Downward-looking 97
      Object on belt 97
  miscellaneous global variables 109
  object 65
    attached to robot (general case) 96
  program
    brightness, adjusting image 89
    calibrating with HPS data 294
    calibration menu 95, 96
      Camera only 95
    camera
      adjustment 89, 90
      current virtual camera 88
    changing current virtual camera 88
    contrast, adjusting image 89
    copying calibration between cameras 87
    copying the program 72
    exiting the program 84, 85
    grip transformation 108
    LEFTY versus RIGHTY configuration 294
    loading old calibration data 85
    RIGHTY versus LEFTY configuration 294
    robot number, current 88
    selecting a different robot number 88
    status display 83
    storing current calibration 85
    testing the calibration 86
    threshold, adjusting binary 90
  status display 83
  testing 86
  transformation 109, 226
Calibration 54
Calls, service 27
Camera
  adjustment
    aperture 89
    gain 90
    offset 90
  cables 315
  calibrating 54
  calibration 54, 55
    programs 54
  current 83
  image surface 37
  imaging 285
    surface 37
  resolution 284
  scale factor 285

- scale factors 286
- virtual 83, 88

Camera-only calibration 95
Cameras
- high-resolution 46
- medium-resolution camera 45
- motion device related 54
- Panasonic GP-MF 702 45
- pixel-clocked 45
- shuttered 45
- Sony XC-77/RR 46
- supported by Adept 286
- supported by AdeptVision VXL 45
- using fixed-mount with a robot 225

Camera-to-robot transformation 64, 109
CHANGE virtual and/or physical cameras 88
Changing current virtual camera 88
Character recognition 185
Color filters 292
Command syntax 52
Compatibility 20, 60
Complete Inspection Vision Program 211
Components of the vision location 233
CONFIG 33
Consistent environment 41
Contrast, adjusting image 89
Controller
- description 32
- installation 44

Controller and vision processor 32
COPY calibration between virtual cameras 87
Copying
- calibration data between cameras 87
- program disk file 72

Correlation 170, 181
- creating template 181
- naming templates 181
- template
  - matching 181

Creating
- correlation template 181
- prototypes 171

Current virtual camera, changing the 88
Custom Calibration Sheet, using a 299
Customer Service
- phone numbers 27

D

Defective pixel compensation 321
Defining
- a tool area-of-interest (AOI) 146
- an image buffer region 149

Deleting
- prototypes 191
- vision models 191

DETACH 33
DEVICE 142, 318–323
- and virtual frame stores 318
- input/output format 320
- instruction used with vision 318

Diffuse 290
- lighting 290

Digital I/O 33
Directional 291
- lighting 291

DISABLE 123, 262
Disabling switches 123
Display
- mode options 117
- modes 117
  - frozen 117
  - graphics 117
  - live 117
- vision window menu 327
- vison window menu 117

Display mode, live 117
DISPLAY.CAMERA 266
Displaying vision models 191
DO monitor command 140
Downward-looking stationary camera (using vacuum gripper) 97
DSP/NSP Switch 313, 315
Dynamic binary rulers 158

E

Edge weights 178
- prototype parameter 178

Edge/Region
- data boxes 176
- radio buttons 176

Edit buttons 175
Editing
- operation data box 176
- prototypes 172

Effort level 178
- prototype parameter 178

Elements of vision calibration array 106
E-mail address 27
ENABLE 123, 262
Enabling/disabling switches 123
Environment, consistent 41
Error
  handling 246
  information 322
Establishing VFEATURE values 270
EVI module settings 315
Example
  changing the number of virtual frame stores 323
  switch and parameter settings 127
Executing
  VDISPLAY from the menu 117
  VPICTURE from the menu 115
Exit to system monitor 84
Exiting the calibration program 84, 85
External trigger 254

F

Feature classes 281
Field acquires
  selecting 92
Field of view
  calculating 284
Filtering and special effects 292
Finder tool polarity 162
Finder tools 39, 160, 160– 163
  defined 39
  search polarity 162
Fine edge rulers 159
Five-axis vision transformation 235
Fixed-mount camera 64
  calibration 55
  transformation 55
  using a 225
  with a robot 225
Focal length
  formula for 284
Focal length, formula for 284
Font planning 184
Font similarity matrix 185
FONT_OCR font name convention 183
Fonts
  deleting 191
  displaying 191
  loading 190
  naming convention 183
  planning 184
  renaming 192
  storing 189
  training OCR fonts 183
Formula
  focal length 284
  resolution 286
Frame
  (frozen) Modes 118
  acquires
    selecting 92
  buffer size, changes to 315
  buffers 251
  relative inspections 255
  store areas 251
  stores 146
    virtual 146
Frame-relative inspections using VDEF.TRANS 258
Frames 40
  reference 40

G

Gain, video 90
GETC 33
Getting help 27
Global variables
  ac.config[ ] (real array) 93, 110
  ac.dot.loc (location) 99, 101
  ac.nominal[ ] (location array) 93, 110
  ac.offset[ ] (location array) 94, 109
  to.cam[ ] (location array) 109
Graphics
  display mode 117
  terminal 32
Gray level rulers 159
Grayscale
  defined 35
  image 36
    example 36
  representation of sample matrix 120
Grip transformation 94, 108, 226
  grip.trans (location variable) 226
Guided vision
  arm-mounted camera 229
  example program setup 237
  final part acquire location 234
  fixed-mount camera 225

- overview 40
- program 236
- program example, generalizing the program 246
- programming considerations 246

guided.vis.examp( ) 237

H

High power 25
High-Accuracy Positioning System 69, 294
High-speed
- inspections 250
  - guidelines 250
- trigger 254

HPS option 294

I

ID 48
Image
- adjusting camera settings 89
- binary 36
- grayscale 36

Image-acquisition
- parameters 125, 126
- switches 124

Impact and trapping hazards 26
Information, training 28
init.program( ) 220
inspect.part( ) 211, 241
Inspection
- vision example program 195
- window 39, 165, 166
  - defined 39

Installing the Controller 44
Instructions for Adept Utility Programs 24
Internet 27
IO 33

J

Joint
- camera mounted on robot joint 229

L

LEFTY versus RIGHTY configuration 294
Lens
- and resolution 284
- focal length 284
- selecting 284

Lighting 41
- back 291
- considerations 41
- diffuse 290
- directional 291
- strategies 290
- strobe 291
- structured 291
- suppliers 334
- types of 290

Limit position 178
- prototype parameter 178

Line finder
- example 163
- search area 161
- tool polarity 161

line.line( ) 218
Linear ruler 152
- example 153, 154

Link2 coordinate frame 231
Link-2 mounted camera
- known dot location 101
- non-contact method (lefty/righty) 102
- non-contact method (single config.) 101
- robot can touch calibration object 100

List of
- parameters 266
- switches 263

Live display mode 117
LOAD calibration data from disk 103
load.cam.cal( ) 242
LOAD/STORE calibration data from/to disk 85
- menu options 103

LOADAREA.V2
- details on 76

Loading
- and storing vision models 189
- calibration data 57

Locating the object and begining inspections 201

M

Main Program - inspect.part 211
Maintenance 41
Manuals
  related 23
Matching a correlation template 181
Max verify distance and verify percent 282
Medium-resolution camera 45
Memory
  vision
    allocating 142
Message window 175
Millimeter-to-pixel ratio 60, 61
Min/max area 178
  prototype parameter 178
Miscellaneous global variables 109
Modeling 40
  image correlation 40
  OCR 40
  prototype 40
Models
  vision window menu 191, 329
Modes, live 117
Monitor commands
  DO 140
  VQUEUE 143
Motion 55
Motion devices
  and calibration 54
  and cameras 54
Mounting cameras 47

N

new.pallet( ) 243
Normal (Synchronous) Mode 314
NRM/ASY Switch 313

O

Object
  on moving belt (robot downstream of camera) 97
  recognition 280
  sample 35
ObjectFinder 39
  confirmation 281
  hypothesis generation 281
  refinement 282
  verification 282
OCR 183
  examples 186
  fonts
    defining 183
    naming convention 183
    planning 184
    training 183
  recognizing characters 186
  verifying text 186
Offset, video 90
Ops
  vision window menu 328
Optical character recognition (OCR) 170, 183
Organization 22
Origin
  point of 113
Output the results 208
Overview of guided vision 40
Overview of Pulnix TM-1001 configuration 312

P

Panasonic
  GP-CD 40 45
  GP-MF 702 45
PARAMETER command 125
Parameter examples 125
Parameters 125, 125–126
  and virtual cameras 125
  list of 266
  setting 125, 262
  V.2ND.THRESHOLD 126
  V.EDGE.STRENGTH 119, 126
  V.FIRST.COL 126
  V.FIRST.LINE 126
  V.GAIN 126
  V.LAST.COL 126
  V.LAST.LINE 126
  V.MAX.AREA 126
  V.MAX.PIXEL.VAR 137
  V.MIN.AREA 126
  V.MIN.HOLE.AREA 126
  V.OFFSET 126
  V.THRESHOLD 119, 126
  viewing 263
  vision model 187
Parameters and switches 122–134, 187–

188, 262–266
Part location
  part.loc (location variable) 227
Performing
  correlation matches 181
  frame-relative inspections 255
  high-speed inspections 250
  optical character recognition 183
Perspective
  calibration 93
    transformations 109
  distortion 63
  distortion corrections 63
  transformations 108
Physical
  equipment 30
  vs. virtual cameras 53, 112
Physical/virtual camera relationship 53
Pict
  vision window menu 328
    options 115
Ping-pong frame grabbing 251
Pixel 35
  defined 35
Pixel-clocked camera 45
Planning fonts 184
Point of Origin 113
Polarizing filters 292
POWER
  enabling robot power 55
Preview window 175
Processing windows 40, 166
  (VWINDOW) 164
Program
  "ac.refine.vloc" 303
  "adv.cam.sample" 302
  header and variables declarations 198
  instructions
    DISABLE 123
    ENABLE 123
    executing from system
        prompt 140
    VDEF.AOI 146
    VDISPLAY 115
    VFIND.LINE 160
    VLOCATE 138
    VPICTURE 114
    VRULERI 152, 155
    VWINDOW 164
    VWINDOWI 165
Program code, developing the 198
Programming considerations 210
Proposals 281
Prototype
  editing operations 174
  model parameters 188
  model switches
    and parameters 187
  model switches 187
  parameters 177
    assign cameras 178
    edge weights 178
    effort level 178
    limit position 178
    min/max area 178
    verify percent 178
  parameters vs. system
      parameters 177
  recognition
    reverifying 188
  training 170–178
  training hints 177
Prototype-relative
  inspection 180, 257
  part acquisition 180
Prototypes 179
  and camera calibration 171
  and guided vision 180
  creating 171
  deleting 191
  displaying 191
  editing 172
  loading 190
  recognizing 179
  reference frame 180
  renaming 192
  storing 189
  using 179
Prototyping 169
Pulnix TM-1001 camera 46
  connectors and switches 313

Q

Questions, application 27
Quick frame grab 114, 115

R

Raw binary rulers 158
READ 33
Reading a table entry 322
Recalibrate the camera, when to 67
Recognizing prototypes 179
Rectangular area-of-interest shapes 148
Reference frames 40
    from prototypes 180
Related manuals 23, 60
Renaming
    prototypes 192
    vision models 192
Resetting a table entry 322
Resolution 37
    calculating 284
    defined 37
    formula for 286
Resolution factors 38
Resolution, accuracy, and repeatability 68
Resolution, formula for 286
RETURN to the main menu 89
RIGHTY versus LEFTY configuration 294
Robot mounted camera 64
    calibration 56
    known dot location 99
    non-contact method 99
    robot can touch calibration object 98
    transformation 56
Robot number
    changing current selection 88
Robot or motion device 32
Robotic Industries Association 24
Robotic safety 24
Ruler
    speed and accuracy 160
    types 158, 159
Rulers 39, 152–160
    defined 39
    dynamic binary 158
    fine edge 159
    gray level 159
    raw binary 158
    speed and accuracy 160
    standard binary 158

S

Safety 24, 41
Sample
    area-of-interest 150
    code for a High-Speed Inspection 252
    gauge face 155
    image buffer regions 151
    object 35, 127
    operation 52
    program for guided vision 237
    vision matrix 118
SCARA robot
    arm mounted camera 229
    with camera on Link-2
        4-Axis 229
        5-Axis 234
Seeds 281
SELECT different robot 88
Selecting a different robot number 88
Serial I/O 33
Service calls 27
Setting
    parameters 125
    prototype parameters 177
    the camera environment 199
    vision
        parameters 262
        switches 262
Setting up
    hardware 44
    software 48
Shutter
    control 314
    dial settings for asynchronous mode 314
Shuttered camera 45
SIG 33
SIGNAL 33
Software tools, summary 39
Sony XC-77 46
Sony XC-77/RR 46
Standard binary rulers 158
Start-up calibration 55
Stationary camera
    calibration object attached to robot (general case) 96
Status
    vision window menu 329, 331
STORE calibration data to disk 103

Storing current calibration 85
Strobe 291
    compatibility 45
    lighting 291
    lights
        compatibility 45
Structured 291
Subprototypes 177
Subroutine
    init.program 220
    line.line 218
    write.vwin 221
Summary of software tools 39
Support
    application support 27
    Internet e-mail address 27
    training information 28
Switch and parameter
    example 128, 129, 130, 131, 132, 133, 134
SWITCH Example 124
Switch settings 313
Switches 123, 123–124
    and parameters 122, 122–134, 187–188, 262–266
        for boundry analysis 136
    image acquisition 124
    list of 263
    setting 262
    V.2ND.MOMENT 137
    V.BACKLIGHT 124
    V.BINARY 124
    V.BOUNDARIES 124, 136
    V.CENTROID 137
    V.FIT.ARCS 137
    V.MIN.MAX.RADII 137
    V.PERIMETER 137
    V.SHOW.BOUNDS 137
    V.SHOW.EDGES 137
    V.SUBTRACT.HOLE 136
    viewing 262
    vision model 187
    vision window menu 123, 330
Switches, enabling/disabling 123
Switches, list of 263
Syntax
    command 52
System
    memory 49
    parameters vs. prototype
        parameters 177
    parameters 90
    safeguards 25

T

Table entry
    reading a 322
    writing a 321
teach.pallet( ) 244
Templates
    correlation 181
    deleting 191
    displaying 191
    loading 190
    matching correlation templates 181
    naming correlation 181
    renaming 192
    storing 189
Terminal 32
TEST current calibration
        (camera-to-robot) 86
Testing calibration 86
Theta capability
    definition of 94
    for a tool 99
Threshold
    adjusting binary 90
TMPL_
    correlation template naming
        convention 181
to.cam (location variable) 226
to.cam[ ] (location array) 109
Tool
    theta capability 94, 99
Training
    for users and operators 24
    information 28
    OCR fonts 183
    prototypes 170
Transformation
    calibration 109, 226
    grip 94, 108, 226
    known dot location 99, 101
    nominal 93, 110
    offset 94, 109
    part location 227
    perspective calibration 109
    vision location 226
Types of lighting 290

Typical AdeptVision VXL system 31

U

User equipment 33
Using
  a Custom Calibration Sheet 299
  a fixed-mount camera 225
  this manual 22
Utility programs
  instructions for use 24

V

V+ Language Reference Guide 24
V+ Language User's Guide 24
V+ Syntax Conventions 52
V.2ND.MOMENT 137, 263
V.2ND.THRESHOLD 126, 266
V.BACKLIGHT 134, 263
V.BINARY 124, 128, 263
V.BORDER.DIST 188, 266
V.BOUNDARIES 124, 136, 264
V.CENTROID 137, 264
V.DISJOINT 187, 264
V.DRY.RUN 264
V.EDGE.INFO 264
V.EDGE.STRENGTH 119, 126, 128, 129, 266
V.EDGE.TYPE 266
V.FIRST.COL 126, 267
V.FIRST.COL system parameter 90
V.FIRST.LINE 126, 267
V.FIT.ARCS 137, 264
V.GAIN 126, 267
  system parameter 90
V.HOLES 137, 264
V.IO.WAIT 267
V.LAST.COL 126, 267
V.LAST.COL system parameter 90
V.LAST.LINE 126, 267
V.LAST.LINE system parameter 90
V.LAST.VER.DIST 188, 267
V.MAX.AREA 126, 267
V.MAX.PIXEL.VAR 137, 267
V.MAX.TIME 188, 267
V.MAX.VER.DIS T 188
V.MAX.VER.DIST 268
V.MIN.AREA 126, 130, 268
V.MIN.HOLE.AREA 126, 130, 268
V.MIN.MAX.RADII 137, 264
V.OFFSET 126, 268
  system parameter 90
V.OVERLAPPING 187, 264
V.PERIMETER 137, 264
V.RECOGNITION 187, 265
V.SHOW.BOUNDS 137, 187, 265
V.SHOW.EDGES 137, 265
V.SHOW.GRIP 265
V.SHOW.RECOG 187, 265
V.SHOW.VERIFY 188, 265
V.STROBE 265
V.SUBTRACT.HOLE 136, 265
V.THRESHOLD 119, 126, 128, 132, 268
  system parameter 90
V.TOUCHING 187, 265
Variables, global 93
  ac.config[ ] (real array) 110
  ac.dot.loc (location) 99, 101
  ac.nominal[ ] (location array) 93, 110
  ac.offset[ ] (location array) 94
  ac.offset[ ] (location array) 109
  to.cam[ ] (location array) 109
VCORRELATE 181
VDEF.AOI 146
VDEF.FONT 183
VDELETE 191
VDISPLAY 115, 127
  displaying the image 115
  examples 116
  syntax 116
  with the two frame stores 252
VDISPLAY, using with different frame stores 252
Verify percent 178
  prototype parameter 178
Version 12.0 new features 21
Version 12.1 new features 21
VFEATURE( )
  setting values 270
  values 141
  viewing values 270, 280
VFEATURE( ) 140, 140– 143, 270– 276, 280
  example 142
  values and interpretation
    for ObjectFinder Models (following VSHOW) 276
    for ObjectFinder Recognition Instances (following

        VLOCATE) 275
    for prototype recognition instances
        (following VLOCATE) 271
    for prototype recognition instances
        (following VSHOW) 273
  values and interpretation 141
VFIND.ARC instruction 207
VFIND.LINE 160
VFIND.LINE Array 161
VFIND.LINE Example 162
VFIND.LINE instruction 205
Viewing
  parameters 263
  switch settings 123, 262
Viewing VFEATURE( ) values 270
Virtual cameras 53, 68
  assigning a number 54
Virtual frame stores 146
  defining 318
  and DEVICE 318
Virtual vs. physical cameras 112
VISION
  vision switch 266
Vision
  basics 35
  calibration 65
    things to remember 67
  calibration array 106
  coordinate system 113
  display modes
    using different 117
  location 226
    vis.loc (location variable) 226
  memory
    allocation 142
    setting allocation 318
  memory allocation 320
  memory vs. system memory 189
  models
    displaying 191
    renaming 192
  parameters 266
  queue 143
  switches 263
  tool data arrays 165
  tools
    arc rulers 155
    defining area-of-interest for 146
    Finder tools 160
    inspection windows
        (VWINDOWI) 165
    linear rulers 152
  transformation 55
    fixed-mount camera 228
  window
    selecting display mode 115
  window menu
    Cam/frame 327
    Display 117, 327
    Models 191, 329
    Ops 328
    Pict 115, 328
    Status 329, 331
    Switches 123, 330
Vision-guided tracking conveyor 260
VLOAD 190
VLOCATE 138
  examples 139
  with prototypes 179
VPICTURE 114
  and VWINDOW 164
  examples 115
  getting an image 114
  options 115
  syntax 114
  using with different frame stores 252
  with different frame stores 252
  with external trigger 254
VQUEUE 143
VRENAME 192
VRULERI 152, 155
  array 152
VSTORE 189
VTRAIN.MODEL 183, 184
  correlation template 181
VWINDOW 164
  and VPICTURE 164
  example 164, 165
  instruction 202
VWINDOWI 165

W

Window 166
  defined 40
  different types 166
  vision, adjusting 90
Workcell
  design considerations 41

WRITE 33
write.vwin( ) 221
Writing a table entry 321

Z

Zoom buttons 175

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